CORNELL
UNIVERSITY
LIBRARY

FINE ARTS LIBRARY

CORNELL UNIVERSITY LIBRARY

3 1924 081 380 952

Cornell University Library

The original of this book is in
the Cornell University Library.

There are no known copyright restrictions in
the United States on the use of the text.

http://www.archive.org/details/cu31924081380952

International Library of Technology
409

Building Construction and Materials

322 Illustrations

Prepared Under Supervision of

W. S. LOWNDES, Ph. B.

DIRECTOR, SCHOOLS OF ARCHITECTURE AND BUILDING CONSTRUCTION
INTERNATIONAL CORRESPONDENCE SCHOOLS

OPERATIONS PRELIMINARY TO BUILDING
LIMES, CEMENTS, AND MORTARS
EXCAVATING, SHORING, AND PILING
FOUNDATIONS
STONE MASONRY
CONCRETE CONSTRUCTION
AREAS, VAULTS, AND RETAINING WALLS

Published by
INTERNATIONAL TEXTBOOK COMPANY
SCRANTON, PA.
1925

FINE
T
45
I61
v.409

CORNELL UNIVERSITY LIBRARIES
ITHACA, N.Y.

Operations Preliminary to Building: Copyright, 1919, by International Textbook Company.

Limes, Cements, and Mortars: Copyright, 1919, by International Textbook Company.

Excavating, Shoring, and Piling: Copyright, 1919, by International Textbook Company.

Foundations: Copyright, 1919, by International Textbook Company.

Stone Masonry: Copyright, 1898, 1899, by The Colliery Engineer Company. Copyright, 1907, 1919, by International Textbook Company.

Concrete Construction: Copyright, 1920, by International Textbook Company.

Areas, Vaults, and Retaining Walls: Copyright, 1919, by International Textbook Company.

Copyright in Great Britain

All rights reserved

Printed in U. S. A.

Press of
International Textbook Company
Scranton, Pa.

409

87257

PREFACE

The volumes of the International Library of Technology are made up of Instruction Papers, or Sections, comprising the various courses of instruction for students of the International Correspondence Schools. The original manuscripts are prepared by persons thoroughly qualified both technically and by experience to write with authority, and in many cases they are regularly employed elsewhere in practical work as experts. The manuscripts are then carefully edited to make them suitable for correspondence instruction. The Instruction Papers are written clearly and in the simplest language possible, so as to make them readily understood by all students. Necessary technical expressions are clearly explained when introduced.

The great majority of our students wish to prepare themselves for advancement in their vocations or to qualify for more congenial occupations. Usually they are employed and able to devote only a few hours a day to study. Therefore every effort must be made to give them practical and accurate information in clear and concise form and to make this information include all of the essentials but none of the non-essentials. To make the text clear, illustrations are used freely. These illustrations are especially made by our own Illustrating Department in order to adapt them fully to the requirements of the text.

In the table of contents that immediately follows are given the titles of the Sections included in this volume, and under each title are listed the main topics discussed.

International Textbook Company

CONTENTS

NOTE—This volume is made up of a number of separate Sections, the page numbers of which usually begin with 1. To enable the reader to distinguish between the different Sections, each one is designated by a number preceded by a Section mark (§), which appears at the top of each page, opposite the page number. In this list of contents, the Section number is given following the title of the Section, and under each title appears a full synopsis of the subjects treated. This table of contents will enable the reader to find readily any topic covered.

OPERATIONS PRELIMINARY TO BUILDING, § 1

Pages
Testing the Soil.................................. 1–11
Characteristics of Foundation Soils................. 1– 5
Examination of Soils............................. 6– 7
Determination of Bearing Capacity of Soils.......... 8–11
Preparation of the Site........................... 12–40
Surveying 12–14
Clearing the Site.................................. 15
Staking Out Excavations........................... 16–36

Staking out excavations without the use of a transit; Use of the level and transit; Staking out excavations with a transit; Setting batter boards.

Sidewalk Protection 37–40

LIMES, CEMENTS, AND MORTARS, § 2

Cementing Materials 1–36
Limes 2– 6

Classification of limes; Manufacture of limes; Properties of lime; Miscellaneous data on limes.

Cements 7–15

Classification of cements; Cement manufacture; Properties of cements; Testing of cements.

Sand 16–18
Mortars 19–36

Proportions of ingredients; Lime mortars; Cement mortars; Properties of cement mortars; Waterproofing of mortars; Coloring of mortars; Grouting and pointing; Quantity of mortar required; Quantities of materials required for mortars.

EXCAVATING, SHORING, AND PILING, § 3

Pages
Excavating 1–18
Excavating Soils Other Than Rock................ 2– 9
Excavation of Rock.......................... 10–11
Depths and Areas of Excavations................. 12–13
Miscellaneous Excavation 14
Filling and Grading.......................... 15
Measurement of Excavation..................... 16–17
Water in the Excavation....................... 18
Shoring, Needling, Underpinning, and Bracing....... 19–32
Shoring 19–22
Needling 23–26
Underpinning 27–30
Bracing 31–32
Piling 33–53
Piles 33
Bearing Piles 34–44
Sheet Piling 45–49
Driving Piles 50–53

FOUNDATIONS, § 5

Introduction 1– 3
Footings 4–39
Preparation of Foundation Beds.................. 4– 6
Design of Footings.......................... 7–20

Loads supported by footings; Wind load; Allowable reductions in loads on footings; Calculation of sizes of footings; Proportioning of footings; Distribution of loads.

Examples of Footings.......................... 21–39

Ordinary footings; Stepped footings; Spread footings; Column footings; Wall footings; Combined footings; Cantilever footings or foundations.

Deep Foundations 40–42
Foundation Walls 43–51

Materials; Foundation walls of various materials; Thickness of walls; Mortar; Openings in walls; Footings at different depths.

Waterproofing 52–58

Conditions that require waterproofing; Examples of various methods.

STONE MASONRY, § 6

Pages
Terms Used in Stone Masonry 1– 7
Parts of a stone; Parts of a wall; Joints.

Classes of Masonry 8–53
Rubble Masonry 8–12
Ashlar 13–19
Trimmings 20–52
Lintels; Sills; Coping; Columns and entablatures; Stone steps and platforms; String-courses, or belt-courses; Stone arches.

Special Stones 53
Handling and Setting Stones 54–61
Shipping and handling cut stone; Setting stones.

Strength, Measurement, and Inspection of Stonework. 62–66
Strength of stone masonry; Measurement of stone masonry; Inspection.

CONCRETE CONSTRUCTION, § 9

Materials and Methods 1–29
General explanations.

Cement 2– 5
Aggregates 6– 7
Proportioning of Ingredients 8–19
Proper proportions; Mixing of concrete; Hand mixing; Machine mixing.

Conveying of Concrete 20–25
Depositing Concrete 26–29
Plain, or Mass, Concrete 30–48
Application of Plain Concrete 30–34
Forms for Plain Concrete 35–45
Surface Finishes for Walls 46–48
Reinforced Concrete 49–87
Strength of Concrete 50–52
Theory of Reinforced-Concrete Construction 53–55
Reinforcement 56–65
Reinforcing materials; Bars and rods; Expanded metal; Wire fabrics.

Application of Reinforcement 66–69
Columns; Beams and floor slabs.

CONCRETE CONSTRUCTION—(*Continued*)

Pages
Examples of Reinforced-Concrete Construction...... 70–77
Forms for Reinforced-Concrete Structures.......... 78–87
Concrete-Block Construction....................... 88–96
Shapes of blocks; Manufacture of blocks; Surface finishes for blocks; Sizes and weight of blocks.

AREAS, VAULTS, AND RETAINING WALLS, § 10

Areas 1–32
Area Walls 2–18
Bracing the soil; Walls of terra-cotta tile; Brick walls; Stone walls; Reinforced-concrete walls.
Area Steps 19–27
Area Floors 28
Area Drains 29–30
Balustrades, Railings, Gratings, and Covers.......... 31–32
Vaults 33–63
Sidewalk Vaults 33–35
Walls of Vaults............................. 36–42
Roofs 43–44
Floors and Sidewalks........................ 45–57
Construction of sidewalks; Concrete sidewalks; Asphalt sidewalks.
Sidewalk Lights 58–63
Retaining Walls 64–73
Description and Principles of Retaining Walls....... 64–70
Materials and Construction of Retaining Walls....... 71–73

OPERATIONS PRELIMINARY TO BUILDING

TESTING THE SOIL

CHARACTERISTICS OF FOUNDATION SOILS

1. General.—The term **soil,** as used in connection with building operations, may be taken to include all the various materials on which building foundations may be supported. The capacity of the earth to support loads depends upon the character of the soils of which it is composed. These may vary from solid rock to the softest soils such as mud, silt, and quicksand. Rock affords the most stable and satisfactory foundation. Gravel, which consists of water-worn particles of rock, is next best. The bearing capacities of hard dry sand, dry clay, wet clay, silt, marshy soil, and quicksand decrease in the order named.

2. Rock.—The term **rock** is applied to masses of solid rock which have endured for centuries and have not been broken up or disintegrated by the action of the elements.

Igneous rocks, such as granite and trap, have at one time been in a melted state and have cooled off in the course of time. These rocks form solid masses which are not easily split. **Stratified rocks,** such as limestones and sandstones, are found in layers, or strata, of varying thickness. These rocks can be split apart with comparative ease in planes parallel to the strata. These planes are the *natural beds* of the rock or of the stones quarried from this rock. The strata may occur in

COPYRIGHTED BY INTERNATIONAL TEXTBOOK COMPANY. ALL RIGHTS RESERVED

nature in a horizontal position or inclined at different angles, as may be seen in a hilly country where excavations have been made in the rock.

3. The **crushing strength of rock** is generally stated in terms of the load per square foot that will crush it. It is determined by testing small cubes of the rock in a testing machine. The crushing strength of rock varies from about 15 tons per square foot, which is the crushing strength of some of the softer varieties of rock, up to as much as 1,800 tons per square foot for the hardest rocks. The load necessary to crush a rock is called the *crushing load.* In calculating the safe load that a given rock will support, the crushing load is divided by a factor which may vary from 2 to 10. In other words, the safe load is from one-half to one-tenth of the crushing strength of the rock. Where no special test is made to ascertain the crushing strength of rock, it can be assumed that sound rock will safely support from 8 to 30 tons per square foot according to the nature of the rock.

Where tests of the rock have been made, it is safe to assume that the rock will bear one-tenth of the load that will crush it.

Under ordinary circumstances it may be said that all rock, except that of the softest and most friable character, will safely sustain any load that may be brought upon it by an average building.

4. The principal danger to be guarded against in building on stratified rock is that the upper layers, upon which the weight of the building rests, may slip on the lower layers if the natural bed of the rock is much inclined. When the strata are level, however, or nearly so, under the entire foundations of the building, stratified rock forms an ideal material for a building to rest upon. It is undesirable to have a building rest partly upon solid rock and partly upon a softer soil, as the building may settle more over the soft soil than over the rock and cause the walls to crack over the junction of the soil and the rock.

Igneous rock, when in the original masses, is the finest material upon which to erect heavy buildings.

5. Gravel.—Gravel is composed of water-worn and rounded pieces of broken rock from which all earthy substance has been worn away by the action of water. If gravel is found in a compact mass and in strata of considerable thickness, it forms an excellent foundation or support for buildings. When building on gravel, care should be taken to see that the stratum of gravel is not resting upon a stratum of soft soil which may be displaced or squeezed out by the load coming upon the gravel. Gravel overlying a bed of dry material, such as clay or sand, can be regarded as an excellent foundation soil; but if the clay is wet, a test to find the crushing strength and also the safe strength of the soil should be made.

The safe loads are usually taken at from 6 to 10 tons per square foot on hard, cemented gravel, and from 4 to 6 tons on loose, sandy gravel, although the use of the lower limit is considered preferable under ordinary circumstances.

6. Sand.—Sand consists of particles of rock that are $\frac{1}{4}$ inch or less in size. *Sandy soils* contain material varying from fine sand to coarse gravel. Dry sand, when confined by surrounding materials so that it cannot move sidewise, is incompressible, and when thus confined forms one of the best foundation soils obtainable. When not strongly confined it is apt to run out from under the foundations of a building and to allow the building to settle. Sand is readily carried away by water, and where such movement is possible, sand forms a treacherous foundation.

The sand usually found in excavations is either *river sand,* deposited in the beds of ancient rivers; or *virgin,* or *pit,* sand, formed by attrition, or the grinding together, of rocks in past ages.

7. Clay.—Pure clay is a silicate of alumina. The clay generally found is a mixture of pure clay and other soils, and, as a rule, contains more or less moisture.

Soils having clay as the principal ingredient vary greatly in hardness, ranging from slate and shale to soft wet or semiliquid clay. The capacity of clays to support loads varies inversely in proportion to the amount of water they contain.

Hard clay, such as slate and shale, will support the same loads as rocks of equal hardness, while soft clays are always dangerous as materials for foundation soils. Soft clay has a tendency to squeeze out from under a foundation wall and cause the wall to settle and crack. Such clay also will shrink in volume if by any chance the water is drained away from it. This also is likely to cause a settlement in a wall built upon it.

Hard pan is a form of clay which has dried out and become hard and which contains gravel and sand and sometimes boulders. It affords an excellent support for buildings.

Hard, stiff clay, when dry, will safely support a load of from 4 to 6 tons per square foot, while wet, soft clay will not carry more than from 1 to 1½ tons per square foot.

8. Marshy Soil.—Marshy soils are formed by the decay of vegetable growths in sluggish water. The plants flourish and die each year and form successive beds of decayed matter, which are loosely packed together and form an unsatisfactory foundation for buildings. The terms *swamp* and *bog* are used in describing such soils.

9. Mud and Silt.—During freshets, rivers bring down large quantities of soil held in suspension, which is deposited in the form of *mud* or *silt* when the waters subside. This soil is called alluvial soil. The value of alluvial soil as a support for foundations varies considerably. Heavy buildings should not be erected on alluvial soil unless it is found that there are firmer strata beneath, to which the foundations may be carried down if necessary.

10. Made Ground.—Made, or artificial, ground may consist of various kinds of materials, such as the refuse of cities, earth and other materials removed from excavations, cinders, ashes, etc. Structures of any importance or size should never be built upon such ground, although suitable foundations may sometimes be found on it for small, unimportant buildings.

11. Quicksand.—Quicksand is very fine sand that is saturated with water and will flow almost as freely as water. This material has no value as a supporting soil. An attempt to excavate in quicksand without previously getting rid of the water contained in it, is about as useless as trying to dig in water itself. If quicksand can be confined by building walls around it or by enclosing it in sheet piling and the water is drained from it by means of pumps, it may be excavated and built upon like common sand.

12. Loam.—Loam is the soil generally found upon the surface of the ground where vegetation grows, and contains a certain amount of decayed vegetable matter. This soil is not suitable for the support of heavy loads and is generally used to top off the grading around a newly finished dwelling, as it affords the best soil for the growth of grass and plants.

13. Mixed Soils.—It is sometimes found that the site of a structure is occupied by several of the soils already described. Rock may be found over part of the site and soft soil over other parts; or the area may be covered by a mixture of loose pieces of rocks or boulders, or by clay or sand. Such conditions are of frequent occurrence. When heavy structures are to be erected on such sites, the existing conditions should be carefully ascertained before designing the foundations of the building.

14. Compressible Soils.—Clay, marshy soils, mud, silt, etc. are often classified as compressible soils, as they yield or flow when subjected to pressures such as the weight of buildings.

15. Conclusions.—From the foregoing description of soils the following deductions may be made:

It is generally safe to build on rock provided that the surfaces of the rock upon which the building rests are made level.

Gravel, even when mixed with small boulders, can be considered as perfectly reliable for supporting any ordinary structure under usual conditions.

Sand will carry very heavy loads if it is confined so that it cannot be carried from under the foundations. Water must also be kept away from it, especially running water that might wash it away.

Clay, when compact and dry, will carry large loads, but water should be kept away from it by means of drainage if necessary.

A thick, hard, compact stratum, overlying a much softer stratum, will often carry a considerable load, the hard stratum floating on the soft as a raft floats on water. It is usually better not to break through such a hard stratum, as it serves to spread the weight of the building over a large area.

Silt, mud, and marshy grounds are not good soils to build upon. The same is true of made ground and quicksand.

EXAMINATION OF SOILS

16. Methods of Investigation.—Before erecting any permanent structure, an accurate knowledge of the character of the soil upon which the structure is to stand should be obtained by examination. If the structure is to be erected in a well-settled locality, this information may possibly be obtained from the history of the adjacent excavations. This should not be relied upon, however, unless the geological formation of the ground is regular and uniform. If the building is to be placed in an unsettled locality, or if it is to be of greater weight than adjoining buildings, maps of the geological formation, if available, should be consulted, as they may furnish valuable information as to the nature of the soil on the site and its probable bearing value.

If the building is an important one and the character of the foundation soil is not known, tests should be made for some distance below the level of the bottom of the foundation walls in order to determine the character of the underlying strata.

17. Tests by Driving Pipes.—The tests may be made by driving into the soil a gas pipe, 2 inches or more in diameter, and withdrawing the pipe from time to time to obtain samples of the material that it has passed through. If the pipe passes through gravel or hard soil, difficulty will be experienced in extracting the soil from the pipe. This method, at best, is crude and should not be used if accurate results are desired.

18. Tests by Boring.—A better method is to drive a pipe about 3 inches in diameter into the ground and then bring up the material by means of an auger, which is turned inside the pipe as shown in Fig. 1. A common auger, such as is used in boring wood, is fitted to a shaft which can be lengthened by screwing on additional sections, and is also provided with a handle such as shown in the figure. This auger is turned five or six times until the bit is filled and is then raised and the material examined. It is then cleaned and the process repeated. Records of the material found at all the depths can be made which will be useful in designing the foundations. When the auger can no longer be raised by hand it may be raised by a block and fall secured to the wooden frame. These borings should be made at several different points on the site.

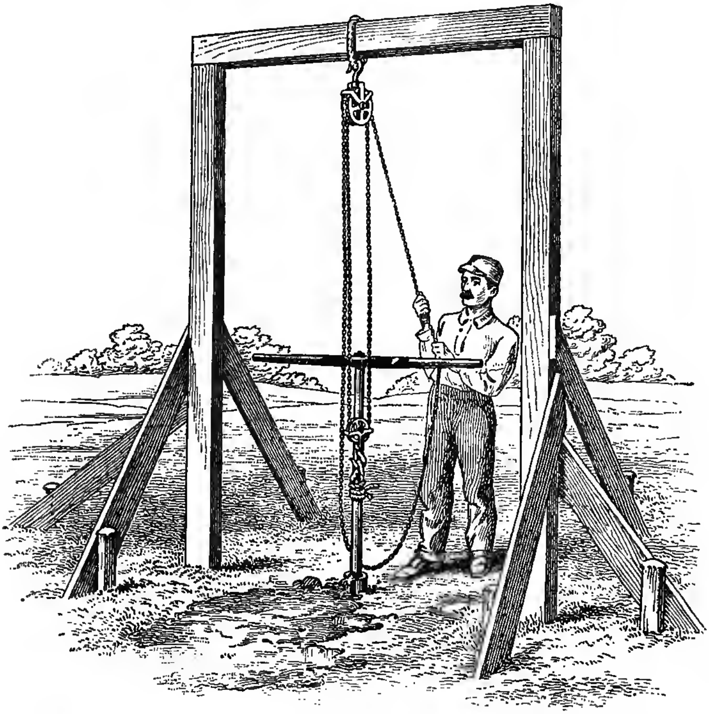


FIG. 1

19. Use of Test Pits.—A simple method of ascertaining the exact nature of the soil for moderate depths below the surface is to dig test pits or open wells as deep as may be desired. The exact nature of the soil for this depth can then actually be observed. If water is encountered it may be necessary to line the pit with sheeting and possibly to use a hand pump to keep the pit free from water.

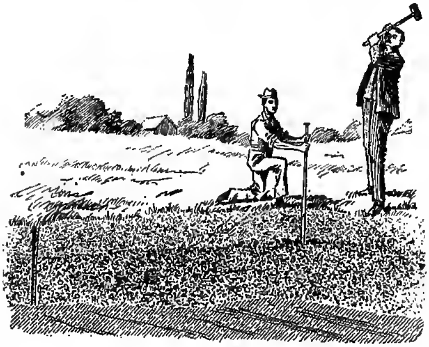


FIG. 2

20. Tests by Steel Bars.—The position of rock near the surface of the ground may be determined by driving a steel rod or a crowbar into the ground by using a heavy hammer, as shown in Fig. 2. The presence of water in the soil near the surface may also be determined by this means. The bar should be driven into the ground at several points in the area to be excavated so as to determine conditions over the entire site of the proposed building.

DETERMINATION OF BEARING CAPACITY OF SOILS

21. Methods of Determining Bearing Capacity. After a full knowledge of the nature of the soil has been obtained, if it is found to be compressible, its actual bearing capacity should be determined by experiment.

In some cases this is done by using an apparatus such as is shown in Fig. 3. This apparatus consists of a mast, or post *a*, 12 inches square in section. Upon this post a platform *b* is fitted and braced so as to receive the load *c*. The apparatus is held in a vertical position by means of guys *d*. The bottom of the post rests on the soil at the bottom of a pit and the load *c* is gradually placed upon the platform until a settlement is noted. The weight of the load just before settlement begins is the greatest load that the soil will bear per square foot of surface.

In testing the bearing capacity of the soil on which the New York State Capitol at Albany is erected, a measured load was applied to a square foot and also to a square yard. For the first test, a timber mast, 12 inches square, held in a vertical position by guys, was fitted with a cross-frame to hold the weights. A hole 3 feet deep was dug in the blue clay at the bottom of the foundation. The hole was 18 inches square at the top and 14 inches square at the bottom. Small stakes, such as shown in Fig. 3, were driven in the ground on lines radiating from the center of the hole. The tops of the stakes were brought exactly to the same level, so that any change in the surface of the ground adjacent to the hole could readily be detected by means of a straightedge. The foot of the mast was placed in the hole and the weights applied. No change in the surface of the adjacent ground was observed until the load reached 5.9 tons per square foot, when an uplift of the surrounding earth was observed in the form of a ring with an irregular curved outline. Similar experiments were made by applying the load to a square yard, with practically the same result. The loads were allowed to remain for some time and the settlements observed.

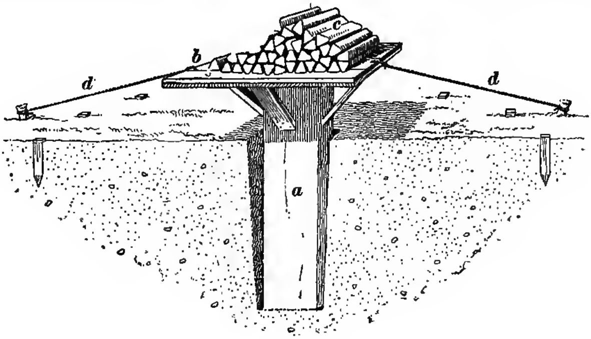


FIG. 3

For firm soils and rock and in cases where the loads are very light, such tests are generally unnecessary.

BEARING VALUE OF FOUNDATION SOILS

22. There is some difference of opinion regarding the safe bearing value of foundation soils, due to the difficulty of arriving at any experimental results that will have a general application. Conservative engineering practice, however, dictates that the greatest unit pressure on the different foundation soils shall not exceed the values given in Table I.

TABLE I

SAFE BEARING VALUES OF DIFFERENT FOUNDATION SOILS

Material	Tons per Square Foot
Granite rock	30
Limestone, compact beds	25
Sandstone, compact beds	20
Hard pan	8 to 10
Shale formation, or soft friable rock	8 to 10
Gravel and sand, compact	6 to 10
Gravel, dry and coarse, packed and confined	6
Gravel and sand, mixed with dry clay	4 to 6
Clay, absolutely dry and in thick beds	4
Clay, moderately dry and in thick beds	3
Clay, soft (similar to Chicago clay)	1 to 1½
Sand, compact, well-cemented, and confined	4
Sand, clean and dry, in natural beds and confined	2
Earth, solid, dry, and in natural beds	4
Alluvial soils	½ to 1½

23. According to the New York City Building Code.—The observance of the requirements of the revised building codes of various large cities is considered good engineering practice, for they usually embody the results of careful investigations and records of long experience. The following, taken from the New York City Building Code, gives an excellent rule that may be safely followed:

In the absence of a satisfactory test of the sustaining power of the soil, different soils, excluding mud, shall be deemed to safely sustain the following loads to the superficial foot, namely:

SOILS	TONS PER SQUARE FOOT
Soft clay	1
Wet sand	2
Firm clay	2
Sand and clay, mixed in layers	2
Fine and dry sand	3
Hard dry clay	4
Coarse sand	4
Gravel	6
Soft rock	8
Hard pan	10
Medium rock	15
Hard rock	40

24. According to the Chicago Building Ordinances.—The following allowable stresses for various soils are specified in the Building Ordinances of the City of Chicago:

(*a*) If the soil is a thick layer of pure clay at least 15 feet thick, without admixture of any foreign substance other than gravel, it shall not be loaded to exceed 3,500 pounds per square foot. If the soil is a layer of pure clay at least 15 feet thick and is dry and thoroughly compressed, it may be loaded not to exceed 4,500 pounds per square foot.

(*b*) If the soil is a layer of firm sand 15 feet or more in thickness, and without admixture of clay, loam, or other foreign substance, it shall not be loaded to exceed 5,000 pounds per square foot

(*c*) If the soil is a mixture of clay and sand, it shall not be loaded to exceed 3,000 pounds per square foot.

PREPARATION OF THE SITE

SURVEYING

25. The Need of Surveying.—Before beginning the erection of a building, it is always desirable and in some cases quite necessary to have the property, upon which the building is to be erected, carefully surveyed by a competent surveyor.

One reason for having such a survey made is that it gives the owner the exact limits of his property so that when he builds he will not encroach upon adjacent properties and make himself subject to lawsuits.

Another reason is that it is necessary that the architect have a map of the property which will enable him to draw his plans intelligently and to arrange the floor levels and the entrances to the building with reference to the grade or surface of the lot as well as to the curb, sidewalk, and adjoining properties.

A third reason for having the property surveyed is that in certain cities the law requires that a map, diagram, or survey showing the location and dimensions of the property shall be filed when application is made for a permit to erect the building.

It is important, in suburban localities, where the streets have not been paved and the curbs have not been set, to ascertain the legal levels of the curb and sidewalk so that the building may be set with reference to them. These levels can generally be obtained from the city engineer or surveyor.

26. The Survey.—In surveying a piece of land, its exact location and the lengths and directions of its boundary lines are determined. Where the surface of the lot is irregular in height, the heights of various parts of its surface with relation to the curb of the street or other fixed point are given.

In surveying lots in cities where buildings are built close together, the existence of party walls and the depth below the curb of all walls adjacent to the lot should be ascertained.

It is necessary, when it is desired to construct a deep cellar, to measure the depth of the sewer below the curb as well as the pitch, or fall, of the sewer. These facts should be determined so that the cellar floor and plumbing fixtures that are located in the cellar can be properly drained.

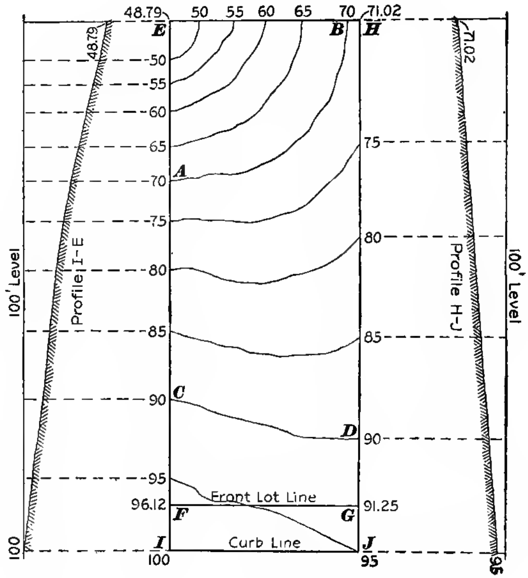
27. The Map or Diagram.—All the facts relative to the location, boundaries, size, and physical characteristics of the piece of property that are ascertained by the survey are shown by means of a drawing called a *map* or *diagram,* or sometimes a *survey.*

28. Staking Out the Property.—When surveying a piece of property, the surveyor marks the corners of the lot by means of stakes driven into the ground when this is possible. The stakes may be of wood or of iron, the exact point to which measurement is taken being marked by a tack on the top of the wooden stake and by a punched hole on the top of an iron one.

There are many cases, especially in closely built cities, where stakes cannot be driven into the ground, and in these cases marks are made upon adjacent buildings or other permanent objects.

29. Contour Maps.—When, as in suburban and country properties, the surface of the lot is broken or uneven, the irregularities should be determined and shown on the map. A map or diagram showing the irregularities in the surface of a lot is called a contour map. In other words, a **contour map** is one that shows the levels or relative heights of various portions of the surface of the lot by means of lines of equal level. These lines of equal level are called **contour lines.** Contour lines are shown at *A B* and *C D* in Fig. 4. These are lines upon the surface of the lot *E F G H,* each of which is at the same level, or height, throughout its length. Thus, the contour line *A B* shows the direction in which a man would have to walk across the lot so as always to be at the same level. The same is true of any other contour line, such as *C D.* Where the contour lines are close together, as at *A E,* the slope of the ground is greater. Where the contour lines are farther apart, as at *H D,* the slope is more gradual.

Contour lines are marked or numbered with reference to the assumed height of some point, such, in the case of Fig. 4, as the highest point of the curb in front of the property. In Fig. 4 this point *I* is marked 100 on the map as representing a level, or height, of 100 feet, though any other convenient height might be used. All the other levels are marked with reference to this point. Thus, if the point *A* is 30 feet below the point *I* it will be marked 70. The contour line *C D* is 10 feet below the point *I* and is therefore marked 90. Such a reference point as *I* is called the **datum.** The point *A* would be referred to as being 30 feet below datum; the point *C* as 10 feet below datum, etc.



(a) *(b)*

FIG. 4

The height assumed for the datum point, or datum, should be greater than the total fall, or drop, in the surface of the lot, which in this case is $100-48.79=51.21$ feet.

30. The contour lines are laid out so that the level indicated by one line is at a definite distance above or below the levels of the lines next to it. This distance is generally taken at 1 foot, 5 feet, or some other convenient distance. For moderate-sized properties 5 feet is the distance between levels that is generally taken. Thus, in Fig. 4, the line marked 85 shows a level that is 5 feet higher than shown by the line 80, and 5 feet lower than the line marked 90.

31. From such a map, the architect can lay out a profile showing the outline or slope of the surface of the lot along any desired line. Such profiles are shown in Fig. 4 at (*a*) and (*b*). At (*a*) is shown a profile along the line *I E* and at (*b*) a profile along the line *H J*.

CLEARING THE SITE

32. Noting Conditions on the Site.—The architect frequently specifies that the contractor shall inspect the site upon which the building is to be erected and note existing conditions. It is advisable for the contractor to do this, as he will obtain information that may have an important bearing upon his estimate. He can observe the nature of the soil and whether there is rock to be excavated. He should notice the condition of adjacent buildings, if there are any, and note if there will be any need of supporting their walls when excavating. He should also note any trees, boulders, or other obstructions on the lot that must be removed and all other conditions that would affect the execution of his work.

33. Wrecking.—If there are old buildings on the lot, that must be removed, the work of *wrecking,* or tearing them down, is generally given to a *wrecker,* or contractor who makes a specialty of that kind of work.

If there are any old materials in the building which have value, the wrecker will sometimes remove the building in consideration of receiving this material. If there are no materials of value in the building, the work of wrecking it will have to be paid for. Occasionally there is material of such value in the building that the owner may be paid a consideration for the privilege of removing the building.

34. In wrecking an old building, the old material should be removed carefully, so as not to imperil life and limb. When the removal of the material is likely to create considerable dust that will be annoying to passers-by, it should be wet. The old material when it consists of brick, mortar, and plaster is generally lowered from the upper stories through rough wooden chutes which deliver it directly into wagons.

It should be understood that the wrecker is to remove all rubbish incidental to the wrecking of the building.

35. The contractor may find it to his interest to do the wrecking himself, and may be allowed to use some of the old material, such as brick and floorbeams, in the construction of the new building if the material is in good condition and is suitable.

36. Clearing the Site.—It is sometimes necessary to cut down trees and bushes and clear off rocks, boulders, and other rubbish from the site before excavation proper can be begun. This work is generally done by the contractor.

37. Protection of Trees.—Trees, bushes, and other objects that it is desirable to preserve from injury should be carefully boxed up during the progress of the work.

STAKING OUT EXCAVATIONS

38. Duty of Contractor.—In architects' specifications it is generally stated that the contractor is to lay out the lines of the building on the lot and be responsible for the accuracy of his work. For buildings of importance it is often specified that the contractor shall employ a competent surveyor to lay out the lines of the building. In either case it is generally required that the contractor shall have the building staked out and be responsible to the owners for any errors in doing so.

The architect should furnish all necessary plans and other needed information for laying out the building and should verify the accuracy of the work as laid out by the contractor. He should not, however, assume any responsibility for errors in the work.

39. Staking Out Excavations on City Lots.—On city lots, where the building is to occupy the full width of the lot and where the front of the building is to be in line with the fronts of adjacent buildings, there is little need of staking out excavations. The corners of the lot, as marked by the surveyor, form a sufficient guide for this work.

In some cases a special arrangement is made between the owners of adjacent properties by which one wall is built on the line dividing the two lots instead of two walls, so that one-half of the wall is on each lot. This wall is then used in common for the support of floors and roofs of both buildings. Such a wall is called a *party wall* and its use affords an economy in material and space.

STAKING OUT EXCAVATIONS WITHOUT THE USE OF A TRANSIT

40. When buildings are to be located on suburban or country sites and are kept well within the boundaries of the lot, the excavations can be easily laid out without the aid of a transit. This is particularly true when the surface of the lot is practically level.

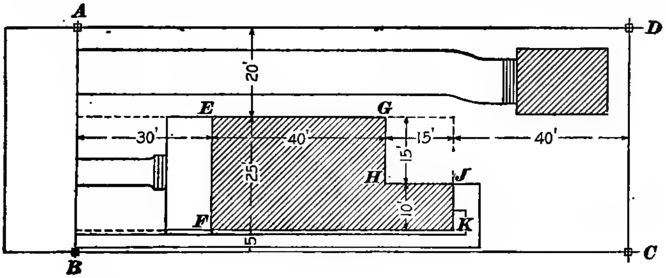


Fig. 5

In Fig. 5 is shown the plan of a lot, the corners *A, B, C, D* of which have been marked by a surveyor. Assume the size of the lot to be 50 ft.×125 ft. and the position of the house upon the lot to be as shown at *E G H J K F*. The lines *E G*, *G H,* etc. represent the outside lines of the basement or cellar walls and their lengths are obtained from the figures on the cellar plan of the house.

The position of the front wall *E F* of the building is determined by the taste of the owner, who is generally influenced by the positions of neighboring buildings. In Fig. 5, the front wall is shown 30 feet back of the front lot line *A B,* also called the *fence line* and the *building line*.

A space, 5 feet in width, has been left for a passage from the street to the rear entrance. The house is 25 feet in width. This leaves a space 20 feet wide for a garden or a roadway to a garage or stable in the rear of the house. It also secures light and air for the principal rooms of the house.

41. Staking Out From the Side Lines.—When the lot lines are not covered by fences, bushes, trees, or other objects and the lot is approximately level, lines can be stretched between the surveyor's stakes and the lines of the excavation can be laid off from them by the use of measuring tapes, stout twine, stakes, and nails.

Stretch a twine between the stakes indicated by *B* and *C* in Fig. 6, which is a view of the property shown in Fig. 5. Lay off, as shown in Fig. 6, the distance $B f = 30'$ and drive a stake at *f* so that the 30-foot mark will be about in the middle of the stake. Drive a nail into the stake to mark the exact point of the 30-foot measurement. In locating points it should be remembered that the true marking points are the nails and that the stakes should be placed so that the nails can be driven at the proper points. In driving the nails allow them to project about ½ inch so that the twine may be easily attached to them.

Lay off the distances $B i = 70'$ and $B k = 85'$ and mark the points *i* and *k* as just described.

Stretch a line between *A* and *D* and lay off the distances $A e = 30'$, $A g = 70'$, and $A j = 85'$, marking the points *e, g,* and *j* with stakes and nails.

Stretch a line between the stakes at *e* and *f* and lay off $f F = 5'$, $f E = 30'$. At the points *F* and *E* drive stakes and nails. The corners *E* and *F* of the wall will then be located.

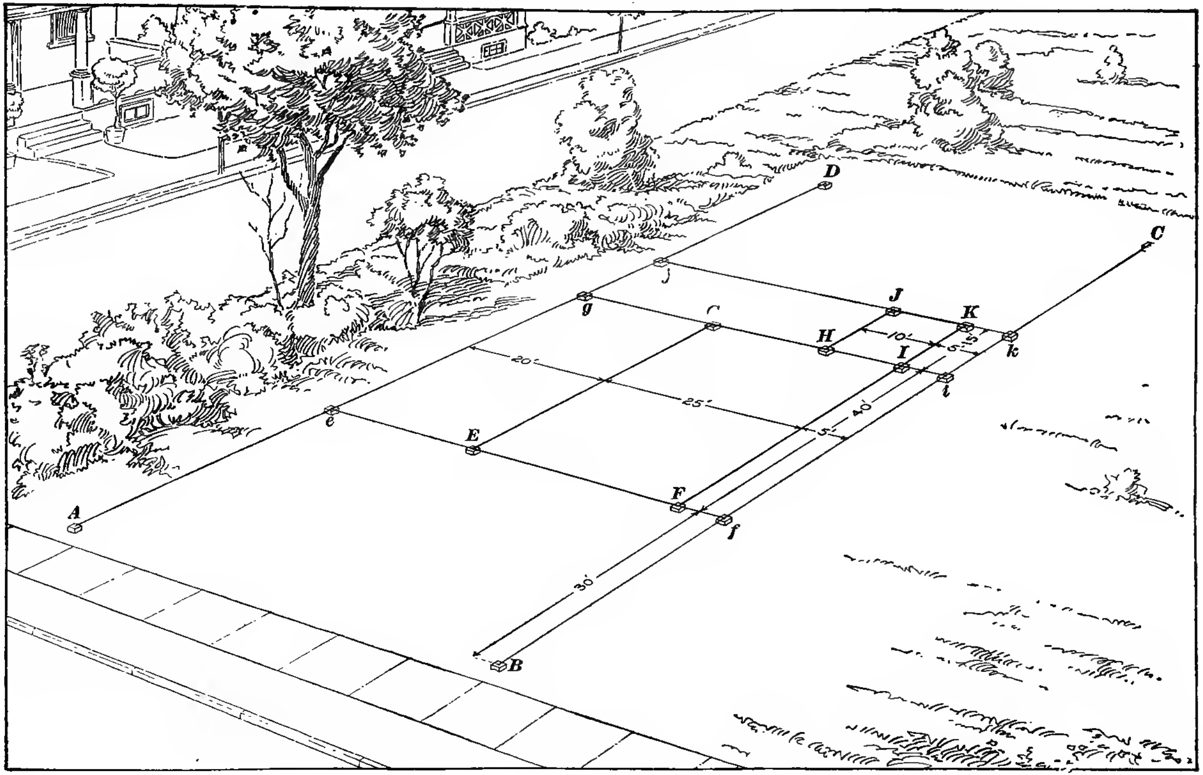


FIG. 6

Lay off similar distances on the line *i g*, and the points *I* and *G* will be determined. Lay off *I H* = 10′ and mark the point *H*. On the line *k j* lay off *k K* = 5′ and *k J* = 15′ and mark the points *K* and *J*. All the corners of the house will then be marked.

42. Staking Out From the Front Line.—When it is difficult or impossible to work from the side lines of the lot on account of various obstacles, the lines for the excavation can be laid out from the front line of the lot.

As shown in Fig. 7, a line is stretched from *A* to *B* to define the front line of the lot. Lay off *B M* = 5′ and *B L* = 30′, and drive stakes at the points *M* and *L*. The next step is to lay off, at the points *M* and *L*, lines that will be at right angles to the line *A B*.

43. Laying Off Right Angles.—To lay off right angles without using the transit, the 3-4-5 method is used. This method is based on the fact that if a right-angled triangle has sides 3 feet and 4 feet in length its hypotenuse will measure 5 feet. The figures 6, 8, and 10 or any other multiples of 3, 4, and 5 can be used in forming right triangles. The larger the multiples the more accurate the results. To apply this method to the case shown in Fig. 7, lay off the distance 6′ from *L* to *b*, and mark the point *b*. Placing the ring of the tape over the nail at *L* and with a radius equal to 8′, scratch a small arc on the ground at the probable location of the point *a*. Placing the ring of the tape over the nail *b*, and with a radius of 10′, scratch another arc across the first arc. The intersection of these arcs will locate, with sufficient accuracy, the position in which to drive the stake *a*.

The next step is to hold the tape *against* the nail in *L* and with the radius 8′ draw an arc with a lead pencil across the *top of the stake a;* then draw a similar arc with the radius of 10′ from *b*. The intersection of these carefully drawn arcs will be the point of the triangle *L b a*.

The line passing through the points *L* and *a* should be at right angles to *A B* at the point *L*, if the measurements have been made accurately.

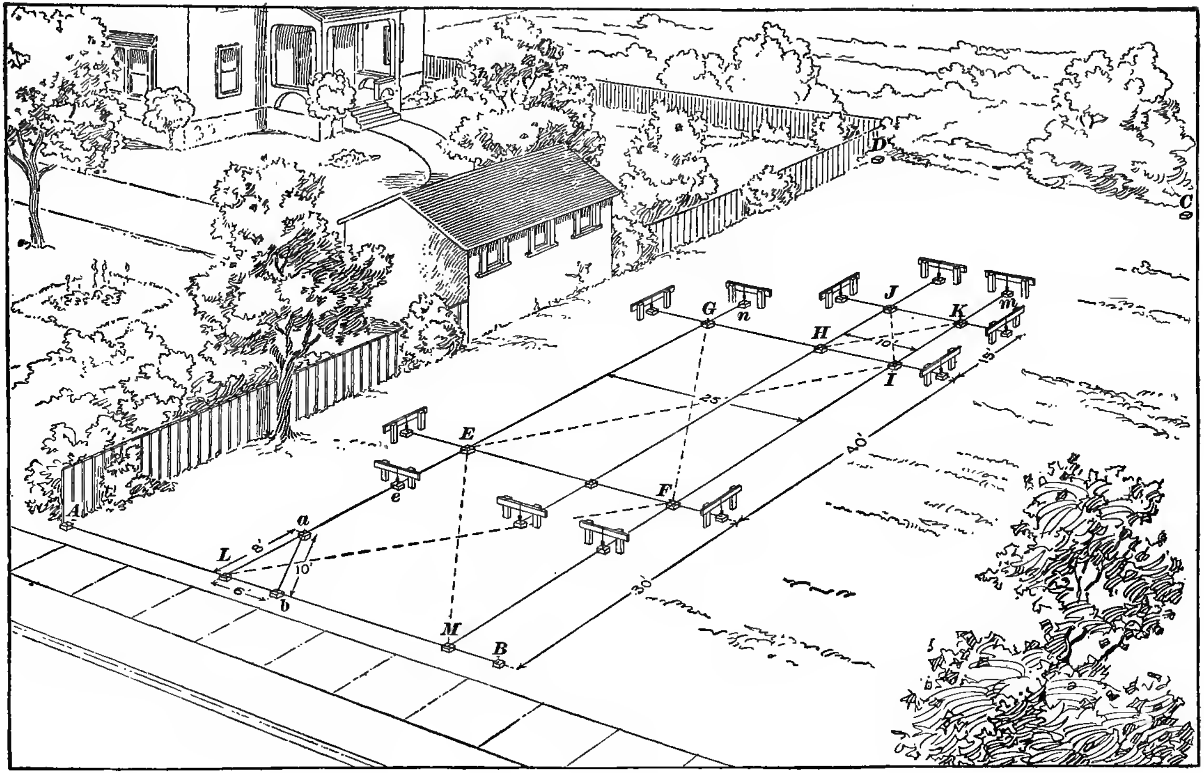


Fig. 7

Extend the line *L a* to the point *n*, making *L n* about 75′ in length. A line *M m*, at right angles to *A B* at *M*, is then laid out in a similar manner.

Measure back a distance of 30′ on the lines *L n* and *M m*, and mark the points *E* and *F* which determine the front line of the house.

44. Checking by Diagonals.—A good precaution to take, at this point, is to verify, or check up, the angles *M L E* and *L M F*. This can be done by measuring the two diagonals *L F* and *M E* of the rectangle *L M F E*. These diagonals should be equal. If they are found to be unequal, then the angles *M L E* and *L M F* are not right angles.

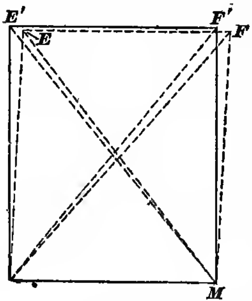


FIG. 8

It will then be necessary to move the stakes at *E* and *F* until these diagonals are made equal.

Thus if, as in Fig. 8, it is found that the diagonals *L F* is longer than *M E*, the stakes or pegs at *E* and *F* should be moved toward the points *E′* and *F′* until the distances *L F′* and *M E′* are equal and the lines *L E′* and *M F′* are equal to 30′ in length.

In this manner, any error that has been made in using the 3-4-5 method can be discovered and rectified.

If the points *E* and *F*, in Fig. 7, require to be changed, it follows that the points *n* and *m* will have to be changed also.

45. Having established the points *E* and *F* accurately, measure back from them 40′ on the lines *L n* and *M m* and mark the points *G* and *I*. Mark the point *K*, 15′ from *I*. Stretch the line *I G* and lay off the point *H*, 10′ from *I*. Measure 15′ from *H* to *J* and 10′ from *K* to *J* and the point *J* will be determined. The rectangle *E F I G* can be checked up by measuring the diagonals if desired. As a matter of precaution this is a good thing to do.

46. Holding the Tape.—In making horizontal measurements with a tape, the tape should always be held in a level position. When it is required to measure the distance between two points one of which is higher than the other, the end of the tape should be held at the level of the higher point, as at *b* in Fig. 9, and the measurement made to the string *d* of the plumb-bob *a*, which is suspended above the lower point *c*.

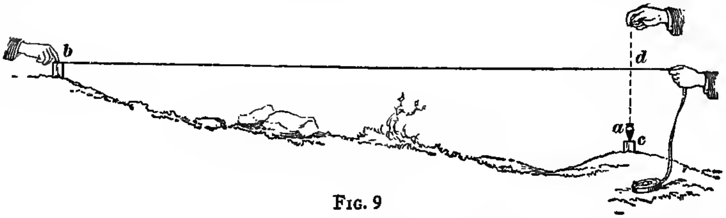


FIG. 9

USE OF THE LEVEL AND TRANSIT

47. Description of the Level.—A level is illustrated in Fig. 10. It consists of a telescope *a*, which is supported on a tripod *b*. Attached to the telescope is a very sensitive level *c*, by means of which the telescope can be adjusted so as to be level. In setting up the instrument for use, the feet of the tripod are placed firmly on the ground or forced into the ground slightly, so that the instrument may maintain its position unchanged, and so that the telescope shall be approximately level. The telescope can then be brought to an exact level by turning the adjusting screws *d*.

The telescope is first pointed in a direction so as to be over two of these screws and these screws are turned until the telescope is brought to an approximate level, as indicated by the bubble in the level *c*. The telescope is then turned at right angles so as to be over the other pair of screws, and is adjusted so as to be approximately level by turning these screws.

The telescope is then turned back to the first position and brought to an exact level and next it is turned to the second position and leveled exactly. These operations are repeated as often as necessary until the telescope is level in any position.

48. The telescope is fitted with an object glass at *e*, and an eyepiece at *f*. These parts consist of suitable lenses which magnify objects seen through the telescope about eighteen times. Between the object glass and the eyepiece the telescope is fitted with either two fine platinum wires or spider webs, called *cross-wires* or *cross-hairs,* which cross the interior of the tube at right angles to each other. One of the hairs is vertical and the other is horizontal. The intersection of the hairs is on an imaginary line which is called the *line of sight.* This line passes through the centers of the lenses, and is parallel to the length of the telescope. As the telescope is revolved or rotated horizontally, the line of sight moves around in a horizontal plane called the *plane of the instrument.*

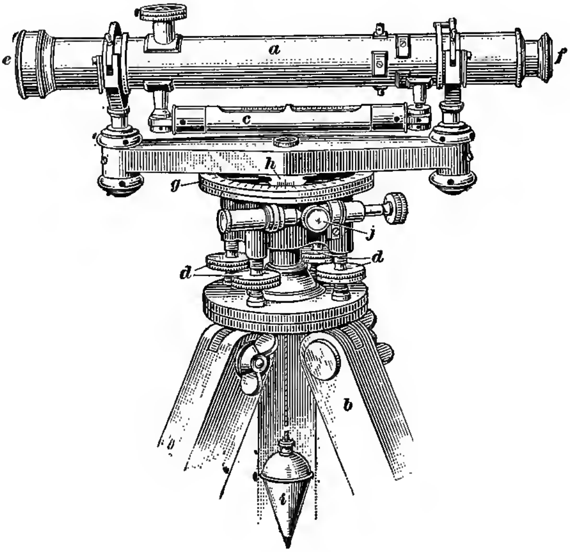


Fig. 10

The horizontal hair is used in leveling. In looking at a point through the telescope, such a point is in the plane of the instrument when it appears to be cut or crossed by the horizontal hair. As the telescope is rotated, all the points that appear to be cut by the horizontal hair are at the same level.

49. Levels used by architects and contractors are usually fitted with a device for measuring angles, which is called a *horizontal limb* and is shown in Fig. 10 at *g*. This consists of a graduated circle, divided into 360 degrees which are each subdivided into two or four parts. When the telescope is rotated, the number of degrees through which it has moved can be read on the horizontal limb. If it is required to turn a right angle, the position of the telescope can be noted before moving and it can be turned exactly 90°.

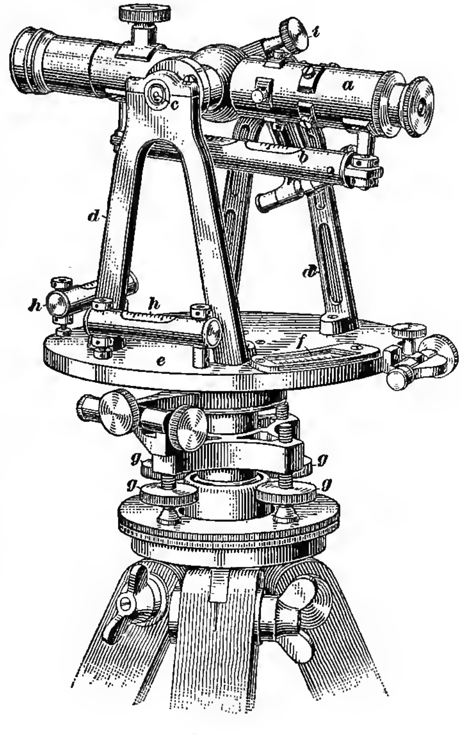


FIG. 11

A device called a vernier, shown at *h*, is sometimes provided in connection with the horizontal limb, which permits of reading these angles with a greater degree of accuracy.

When an angle is to be laid off, the point from which it is to be measured must be marked on the ground and it is necessary to stand the instrument over this point. In order to set up the instrument exactly over such a point a plumb-bob *i* is attached to the instrument so that it will hang directly in the axis of revolution of the telescope. In setting up the level over the point, the tripod is adjusted so that the plumb-bob will be directly above the point or mark, after which the telescope is leveled up and the angle measured off on the horizontal limb. When it is desired to fix the telescope in a given position so that it cannot be rotated, it can be clamped in such a position by means of the screw *j*.

50. Description of the Transit.—The principal difference between the level and the transit is that the telescope of the transit is set on a horizontal axis and rotates in a vertical plane, while the frame supporting this axis can be rotated horizontally. This arrangement makes it possible to point the telescope of a transit in any direction. Since the telescope revolves in a vertical plane, all points cut by the vertical hair are in the same vertical plane. Fig. 11 shows a transit such as is used by builders, in which *a* is the telescope, *b* the spirit-level, and *c* the horizontal axis about which the telescope revolves. This axis is supported by standards *d* fastened to the plate *e*, which revolves in a horizontal plane. The graduations on the plate are shown at *f*. The plate *e* is leveled by means of the four adjusting screws *g* and the two levels *h*.

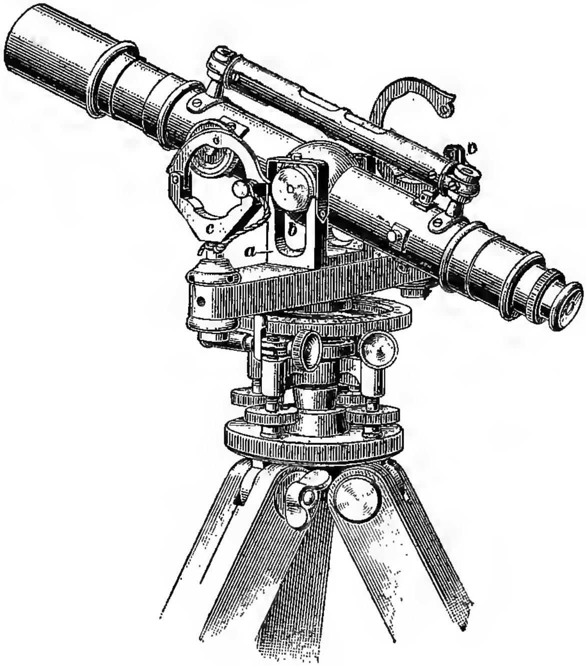


FIG. 12

The transit can be used as a level by bringing the plate *e* to a level position and by clamping the telescope in a level position by the use of the clamp screw *i*. The telescope can then be rotated horizontally in the same manner as the telescope of a level.

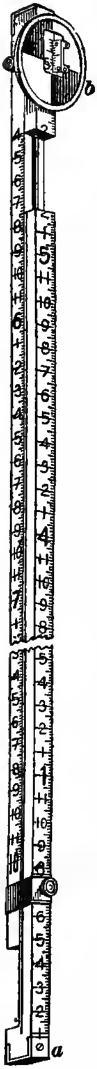


FIG. 13

51. The Convertible Level.—Many concerns manufacture, for the use of architects and builders, a convertible level, as shown in Fig. 12, which can be used either as a level or as a transit. When used as a level, the telescope is supported on the *y's,* or *wyes, c,* from which it can readily be removed. When used as a transit it is supported, as shown at *b,* on a special standard *a,* which is provided with the instrument. When supported on this standard the telescope can be rotated vertically for a sufficient distance for all practical purposes.

The architects' levels and transits are generally made for a much lower price than engineers' levels and transits and are not generally so reliable. A good engineers' transit is an excellent instrument for an architect or builder to use.

52. The Leveling Rod.—In connection with the transit and level a rod called a *leveling rod* is used. This rod, Fig. 13, is made of light-colored hardwood and is graduated, or marked off, in feet, inches, half-inches, quarter-inches, etc. It is formed of two parts which slide one on the other. This allows of the rod being extended. When the rod is extended as far as desired the two parts can be clamped together so that they will not slide. The lower end of the rod is fitted with a metal shoe *a* and the upper part with a metal target *b,* which can be moved up and down on the rod and fastened at any desired point.

When in use this rod should be held as nearly vertical as possible. A person familiar with holding a rod can generally be depended upon to hold it so. The man sighting through the instrument can tell if the rod is plumb in one direction by comparing it with the vertical hair in the telescope, and, if it is not, can direct the man holding the rod to make it plumb.

Any straight rod can be used instead of the standard leveling rod.

53. The Use of the Level.—The level is of great use to the builder in fixing the heights, or elevations, of various parts of a building in their proper relation to each other. It is useful to the architect for measuring the elevations of various portions of a hilly or irregular lot, which provides him with information required to adapt a house to such a lot successfully.

The following description will give a clear idea of the method of using the level in establishing the heights, or elevations, of various portions of a building.

Assume that the level of the first floor has been determined and carefully marked on a stake, an adjoining building, or any permanent object. This will be a convenient point of reference, as the figures on the drawings of the elevations of a building are often given with reference to the floor lines.

The instrument is set up in some convenient position and made perfectly level. It is then sighted toward the object upon which the elevation of the first floor has been marked. The vertical distance between this mark and the plane of the instrument is then carefully measured.

54. Suppose that it is found that the plane of the instrument is 1′ 6″ above the first-floor mark. Then in whatever direction the telescope is pointed the horizontal hair will always mark 1′ 6″ above the first-floor level. From the plans it is found that the excavation for the cellar is to be carried down 8′ 0″ below the first-floor level, and therefore is 8′ 0″+1′ 6″ =9′ 6″ below the plane of the instrument. The measuring rod is then set so that the cross-line of the target is at 9′ 6″, and when the rod is placed on the ground at any point in the excavation the distance of the horizontal line of the target above the plane of the instrument will be the depth of earth still to be removed at that point. The depth can be read off by the man at the level. When the rod is standing so that the cross-line of the target coincides with the horizontal hair of the level, as in Fig. 14 (*a*), the excavation at that point is down to the proper depth.

55. In setting bases for steel columns, the distance of the top of the steel bases below the plane of the instrument is carefully calculated with the assistance of the plans and the target of the measuring rod is set for that distance. When the rod is standing on top of the base and the horizontal line of the target coincides with the horizontal hair, as shown in Fig. 14 (*b*), the base is at its proper level. Where there are several bases in the building that are to be set at the same level they can all be tested without changing the position of the instrument. In such cases the instrument is generally set up at the bottom of the cellar excavation and the level of the cement beds *a* is also tested by the level before the steel bases are set.

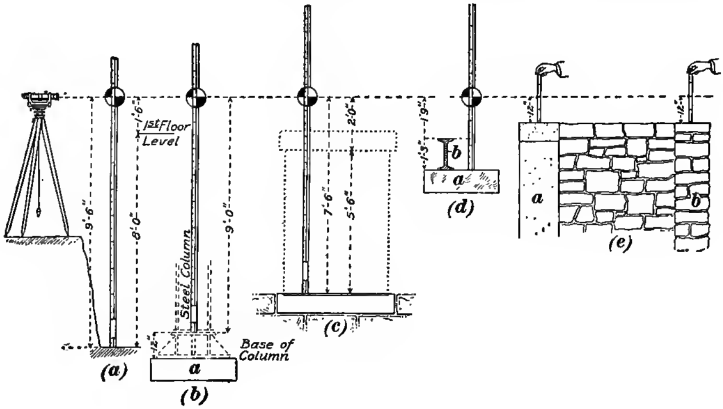


Fig. 14

56. In setting a number of window sills that are to be on the same level, the distance of the tops of the sills below the plane of the instrument is calculated and the target set for that distance. By standing the rod on the tops of the sills, as shown in Fig. 14 (*c*), and adjusting the sills so that the middle of the target will be on the line of sight, all the sills will be at the same level. Both ends of each sill should be tested with the rod to insure their being level.

57. Another case is shown in Fig. 14 (*d*) in which the same general principle is illustrated. A template *a* is to be placed so as to support a steel girder *b*. The distance of the top of the template below the plane of the instrument is found to be 3′ 0″. The target is set with its middle line 3′ 0″ from the foot of the rod. By standing the rod on top of the stone and sighting on the target it can readily be seen whether the stone is too high, too low, or just right. When small dimensions are to be read, a rule or straight stick can be used instead of the rod. In Fig. 14 (*e*), where the distance is 12″, a rule can be used and the level sighted at the rule. In this case the problem is to make the top of the pier *a* level with the top of the wall *b*.

58. In the illustrations already given, the measurements have been taken below the plane of the instrument. They can be taken above this plane, as illustrated in Fig. 15. In this case the problem is to lay out the courses in a brick wall so that they will come right for the panels *a*. The instrument is set up and leveled and a level line can be marked on the wall by making small marks at *b* and *c*. From these points the distances can be measured upwards by means of a rod *d* having the necessary distances marked on it.

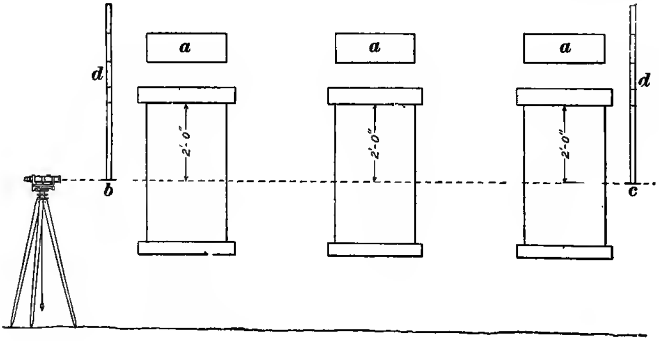


Fig. 15

59. The Use of the Transit.—All the processes described as possible with the level can be performed with the transit. The transit can be used as a level in establishing the elevations, or heights, of various portions of a building. It can also be used in laying off or measuring angles. The fact that the telescope can be moved around in a vertical plane gives the transit a great advantage when it is desired to run and mark straight lines, or to plumb walls or columns.

60. Laying Off Lines and Distances.—An illustration of the methods used in running or laying off a straight line and of marking off different distances on it is given in Fig. 16.

Assume that the point *A* in (*a*) is established and that it is required to lay off a line *A D* 100 feet long. The transit is set up with the plumb-bob *a* directly over the tack in the stake *b*. The plate is then carefully leveled by means of the adjusting screws, the telescope is sighted in the direction *A D*, and the plate is clamped so that the telescope cannot revolve horizontally. The ring of the tape is held against the tack at *A*, as shown in (*b*), and the tape is made taut. At the 100-foot mark on the tape, a line is scratched on the surface of the ground, approximately at *D*, in the manner shown in (*c*). The observer at the transit then points the telescope at this mark and where the line of sight intersects the mark the stake *D* in (*a*) is

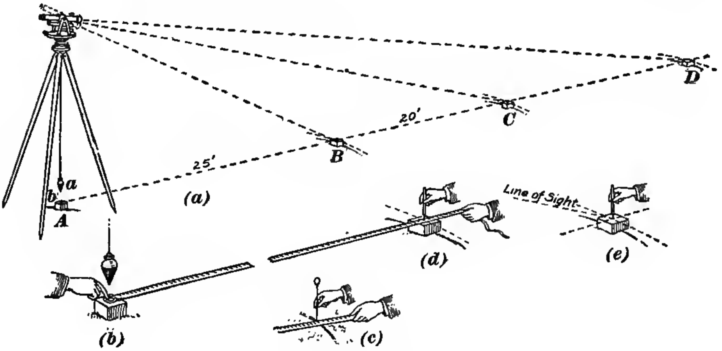
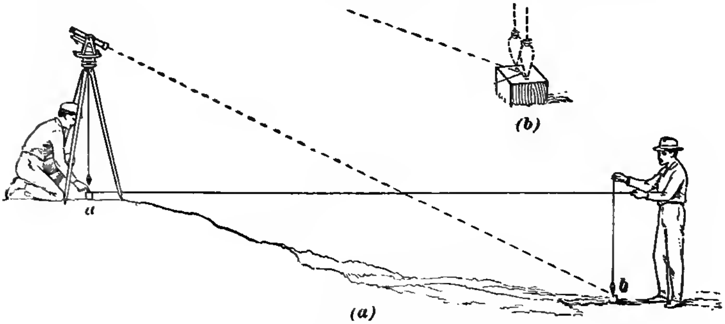


Fig. 16

driven. It then remains to determine the point *D* accurately. This is done by drawing a small arc with a radius of 100 feet across the top of the stake with a pencil, as shown in (*d*), the radius being the tape which is held at the point *A*. The sharp point of a pencil or a tack is then moved along this arc until it is exactly cut by the line of sight of the transit, as shown in (*e*). A mark is made at this point and a tack is driven. When the tack is driven, its position is checked, or verified, by measuring with the tape and by sighting it with the transit. In determining any point in the line *A D*, such as *B* or *C*, the same method is employed. First, the approximate point is found and the stake is driven at that point. Next, the distance is marked by an arc on top of the stake and then this line cut by the line of sight. This gives the exact point required.



(*b*)

(*a*)

FIG. 17

61. When the lot has an irregular surface and the points to be laid off are at different levels, care must be taken to hold the tape level when measuring. The distance must then be conveyed down from the tape to the stake by means of a plumb-bob as shown in Fig. 17. The measurement is first measured off roughly and the direction checked by sighting through the telescope. This will give the position of the stake upon which the final measurements can be made. This is done by the man at the transit holding the tape at *a* and the man at *b* holding the plumb-bob at the desired distance as shown in the figure. By moving the tape slightly from right to left and by dropping the plumb-bob so as to make two or three marks on the stake, as shown in (*b*), the distance will be determined. The man at *a* can then sight the cross-line and the point of intersection can be marked as shown at *c*. This point should be carefully checked by repeating the measurement and the sighting through the telescope.

STAKING OUT EXCAVATIONS WITH A TRANSIT

62. Locating the Excavation Lines.—The plan of a building and its position on the lot are shown in Fig. 18. The stakes or pins *A, B, C,* and *D* are placed by the surveyor to mark the corners of the lot. The plan *E F G H I J K L* shows the outside lines of the cellar walls. The distances of these lines from the lot lines are also given. In Fig. 19 is shown a bird's-eye view of the lot and the lines of the excavation.

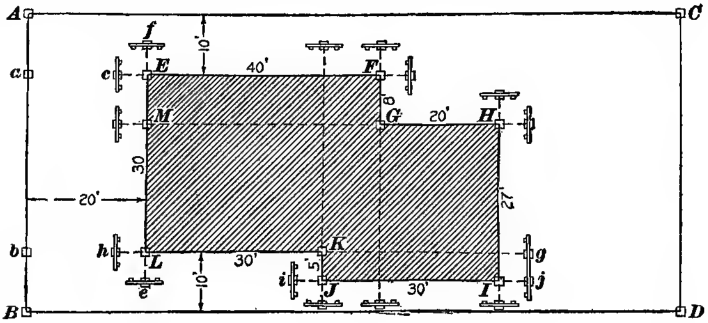


Fig. 18

The transit is set up over the point *A*, Fig. 19, with the plumb-bob directly over the nail in the peg. In case iron pins have been used to mark the corners of the lot, the plumb-bob should be over the surveyor's mark or hole in the pin. The instrument is then leveled up and the telescope sighted at the mark *B*, after which it is clamped so that it cannot be rotated horizontally.

63. In staking out a building it is desirable to locate the corners of the building, also stakes for the location of the batter boards, which are shown in exaggerated size in the illustration. These stakes are placed at a uniform distance of 5 feet from

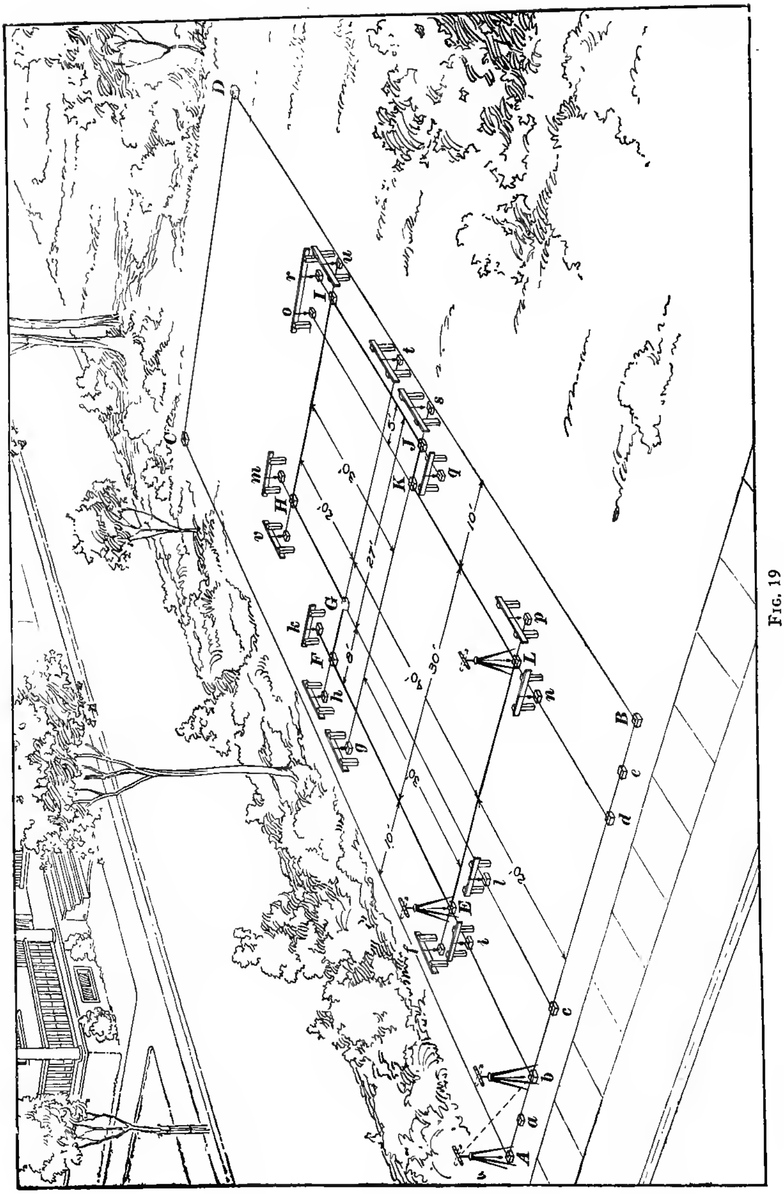

D
C
I
o
r
u
t
s
J
K
q
m
H
v
G
k
F
h
g
L
p
n
B
c
d
E
l
i
f
e
b
a
A
5'
30'
3'
27'
10'
8'
40'
30'
10'
30'
3'

FIG. 19

the walls of the building in this case. Having determined this distance and having consulted the plan, the next step is to lay off and mark a number of points on the line *A B* from which all the stakes required may be laid out.

On the line *A B* lay off the distances $A\,a = 5'$, $A\,b = 10'$, $A\,c = 18'$, $A\,d = 40'$, and $A\,e = 45'$. Mark each of these points with a stake and nail.

Set the instrument up over the point *a* and sight the point *B*. When *B* is accurately cut by the vertical hair, rotate the telescope 90° so that it will point at right angles to *A B* in the direction *a f*. Measure off the distances $a\,f = 20'$, $a\,g = 50'$, and $a\,h = 60'$. Set the instrument up at *b* and lay off $b\,i = 15'$, $b\,E = 20'$, $b\,F = 60'$, and $b\,K = 65'$. In the same manner set the instrument up at *c*, and lay off the points *l, G, H,* and *m*; also at *d* and mark the points *n, L, K,* and *o*. From the point *e* lay off the points *p, q, J, I,* and *r,* and from *B* lay off the points *s, t,* and *u, B s* being 50′, *B t* 60′, and *B u* 80′.

64. Another method of locating the stakes required in staking out the building is first to set up the transit over *A* and lay off the distance *A b*. Then set up the instrument at *b* and mark off the points *i, E, F,* and *k*. Next, set the instrument over *E* and lay off the points *f L* and *p*. Then from *L* lay off the points *n, K,* and *o*. In succession set up the instrument at all the other corners of the building, as at *K, J, I, H,* etc., and lay off all the points that can be sighted from each.

65. Still another method of staking out an excavation makes use of *batter boards,* which are boards nailed to stakes as shown in Fig. 19; the method of setting them will be described later. These batter boards are set up approximately, and the surveyor or the contractor then makes marks directly on them without using pegs. This method is a practical one, but has the disadvantage that if the batter boards are moved or displaced the mark will be lost. If, however, a peg or stake has been driven to locate the batter boards, the batter board can again be set up according to the peg, with very little trouble.

SETTING BATTER BOARDS

66. Purpose and Use of Batter Boards.—When the excavation for the foundations is being done, the stakes marking the corners of the cellar walls are sure to be disturbed and the exact location of the corners lost. Batter boards are therefore placed near the corners and elsewhere, where necessary, to preserve the corners and lines.

Batter boards, or *line boards,* consist of lengths of boarding nailed to stakes that are firmly driven into the ground to mark the position of the building on the lot. They are generally placed at least 5 or 6 feet away from the outside of the excavation so that they will not be disturbed by dirt thrown out or by building materials placed close to the excavation. They are also not likely to be displaced if the edge of the excavation should cave in as it is apt to do when the soil is soft.

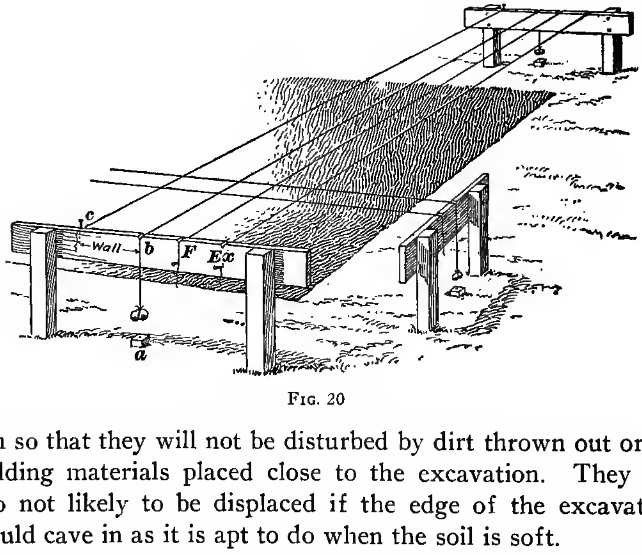


Fig. 20

Batter boards are shown in Fig. 20, also in Figs. 7 and 19. On the batter boards in Fig. 20 are shown notches *c* and *b* locating the inner and the outer lines of the wall, notches *F* for the outer line of the footing under the wall, and notches *Ex* to indicate the limit of the excavation. At *a* is shown one of the stakes which were driven when the excavation was staked out, and the notch *b* is cut directly above it. Very often the marks on the boards are made by driving nails in the upper edge as shown at *c*. The notch *b* is cut directly above the stake *a* and the other marks or notches are measured off on either side of it.

Lines are stretched from the notches in one board to the corresponding notches in another board, as shown in Fig. 20. These lines will be directly over the excavation lines and over the lines of the walls and footings. Thus, a line stretched between the notches *Ex* will locate the outside line of the excavation, and a line between the notches *F* will give the line of the footings.

The tops of the batter boards are usually set at some uniform level, such as at the level of the top of the foundation walls. This level can then be used as a guide in building these walls.

67. Measuring Down From the Lines.—When working on the walls at the bottom of the excavation it is necessary to carry the lines down so that they can be used at that level.

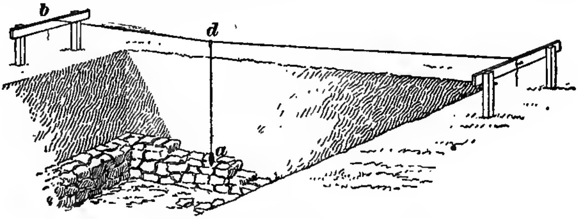


FIG. 21

This is done, as shown in Fig. 21, by suspending a plumb-bob from the lines that are stretched between the batter boards. The plumb-bob *a* is held on the line by means of a loop *d*, which allows the plumb-bob to be run backward or forward along the line *b c* so that any point perpendicularly below the line can be found.

SIDEWALK PROTECTION

68. Sheds, Bridges, and Temporary Sidewalks. In many cities the laws require that, during the erection of a building or while a building is being torn down, *sheds* shall be built over the sidewalk for the protection of pedestrians. In cases where the excavation is to be carried out under the sidewalk, temporary sidewalks must be provided. These sidewalks are supported on bridges which consist of the timber construction built to support the temporary sidewalk. In Fig. 22 are shown a shed, and a temporary sidewalk which is supported by a bridge.

69. Sheds.—Sheds are made of heavy posts *a* about 8 inches square, sills *b* 6 in.×8 in. in size, and girders *c* which are 8 in.×8 in. or 8 in.×10 in. These are bolted or spiked together by means of battens *d*, made of 2″×8″ planking, and braced by the cross-bracing *e*, 2 in.×6 in. in cross-section. These braces are spiked to the timbers.

Resting on the girders are the floorbeams *m*, which should be at least 3 in.×10 in. in section and spaced not to exceed 2 feet on centers. Upon the floorbeams, flooring not less than 2 inches in thickness is nailed. The flooring forms a platform which serves to protect pedestrians from falling building material, and as a place to receive building materials, such as brick, stone, and steel. It is also often used by the stone cutter as a convenient place to cut and fit stones that may be used in facing the front wall of the building. A protective fence or railing *f* is often placed around the sides of the platform to prevent workmen from falling off. It is generally omitted from the street side of the platform so that it shall not interfere with the handling of materials.

It is desirable that the platform be made waterproof, but this is not always done. Sometimes a separate roof is constructed underneath the platform and consists of roofing boards supported on rafters which are nailed to the sides of the timbers and covered with a waterproof paper. This is not shown, however, in the figure.

A heavy timber *k* is placed against the curbstone to prevent wagons from hitting the posts.

70. Bridge and Temporary Sidewalk.—A temporary sidewalk *g* is shown supported on a bridge made of stout timbers such as shown at *n*, which are spiked or bolted to the posts *a*. These sidewalks are often raised a few feet above the normal level of the sidewalk, in which case suitable steps *i* are provided at each end. One reason for elevating the tem-

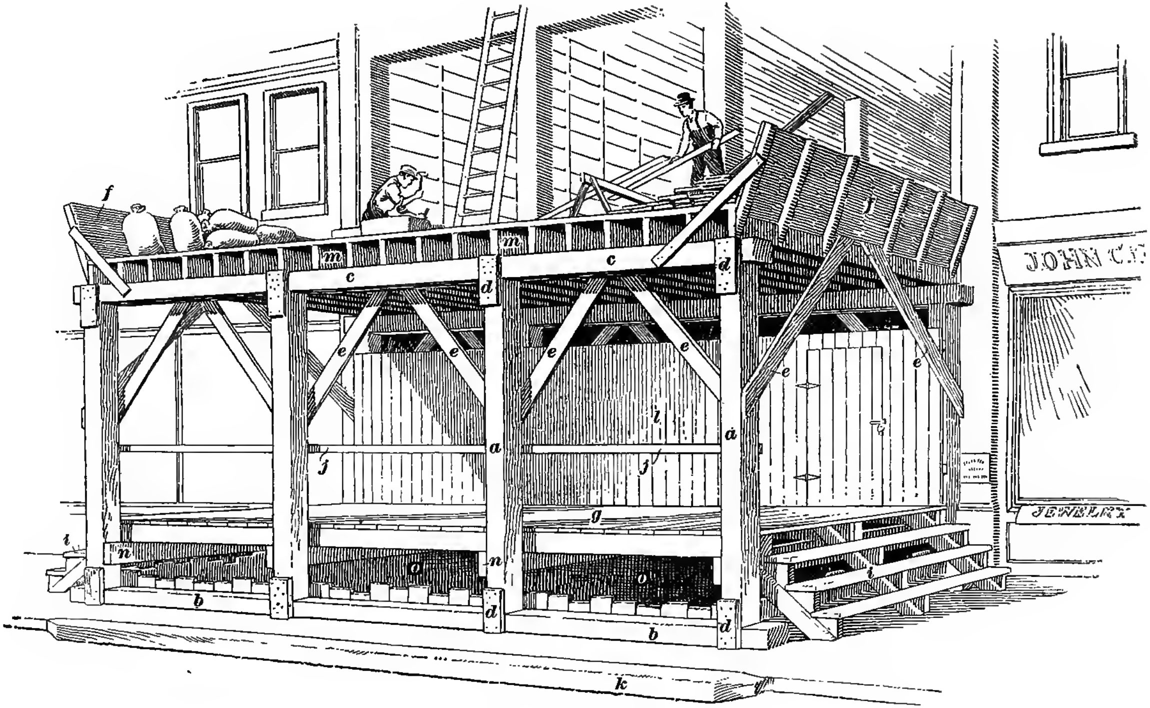


FIG. 22

porary sidewalk is to obtain the spaces *o*, through which sand, brick, and other building materials can be delivered into the building. A railing *j* is generally provided on the street side of the sidewalk and either a railing or a tight board fence *l*, on the building side. A fence is better than a railing, as it prevents pedestrians from stopping on the bridge to view the building operations and interfering with traffic.

LIMES, CEMENTS, AND MORTARS

CEMENTING MATERIALS

INTRODUCTION

1. The **cementing materials** that are used to join together the individual pieces of material used in building walls of masonry, whether of stone, brick, or terra cotta, are the different kinds of mortars formed of lime, cement, and sand. These mortars fill in the spaces between the blocks and make the walls built of these blocks air-tight and impervious to moisture. The mortar when hardened also contributes to the strength of the wall, since a wall is no stronger than the mortar joints between the stones. The best mortars are, therefore, the ones that have the qualities of strength and imperviousness to air and water.

The cementing materials which most completely fill the requirements are limes and cements which are obtained by the heating, or *calcination,* as it is called, of minerals composed wholly or partly of lime, or calcium oxide. The different compositions of these minerals and the different proportions in which they are mixed together result in the various products known as limes, cements, hydraulic limes, hydraulic cements, etc.

2. Use of Cementing Materials.—Cementing materials such as described in this Section and which are used in building construction, have three principal uses; namely: (1) As materials to hold other bodies together; (2) as materials with which to coat parts of structures; and (3) as building mate-

COPYRIGHTED BY INTERNATIONAL TEXTBOOK COMPANY. ALL RIGHTS RESERVED

rials in themselves. The first use is illustrated by the mortar between stone and brick; the second by the plastering materials used to coat walls; and the third, by concrete walls, footings, piers, pavements, etc.

3. Classification of Cementing Materials.—The cementing materials used in building construction will here be classified under two headings, *limes* and *cements.*

LIMES

CLASSIFICATION OF LIMES

4. Chemical Classification. — Limes are classified chemically as *calcium limes, magnesium limes,* and *hydraulic limes.*

Calcium limes contain 85 per cent. or more of calcium oxide. A calcium lime containing over 90 per cent. of calcium oxide is classified as a *high-calcium lime.*

Magnesium limes contain 10 per cent. or more of magnesium oxide. Those containing 25 per cent. or more of magnesium oxide are classified as *high-magnesium limes.*

Hydraulic limes contain a considerable amount of silicate, aluminate, or ferrate of lime. These substances give the limes the property of setting under water, which calcium and magnesium limes will not do. There is also enough calcium oxide in hydraulic lime to cause it to slake when water is added. Hydraulic limes are not used to any considerable extent in America, consequently they will not be considered further here.

5. Common Limes.—Calcium and magnesium limes are generally known as *common limes.* Common limes are divided according to their working qualities into two classes; namely, *fat,* or *rich,* limes, which contain a high percentage of calcium oxide, and *poor, lean,* or *meager,* limes.

6. Classification Commercially.—Limes are also classified according to the form in which they are sold, as follows:

1. *Selected lump lime,* which is well-burned lime from which ashes, core, clinker, and other foreign substances have been removed.
2. *Run of the kiln,* which is well-burned lime just as it is taken out of the kiln without sorting or cleaning.
3. *Ground,* or *pulverized, lime,* which has been reduced in size to pass through a ¼-inch screen.
4. *Hydrated lime,* which has been slaked and is obtained in the form of a fine dry powder.

MANUFACTURE OF LIME

7. Common Lime.—Lime is made by the calcination, or *burning,* of limestone in kilns. The burning is done at a temperature of from 1,400° to 2,000° F. and drives off a gas called carbon dioxide, leaving the stone in the form of lump lime, so called because it consists of burned lumps of stone. If the lime is underburned or overburned it will slake slowly and unevenly and will be unfit to use.

8. Hydrated Lime.—Hydrated lime is a thoroughly slaked fat lime in the form of a fine powder. It is prepared by crushing and grinding lump lime and then sprinkling water over it. The operation is performed by placing the ground lime in a shallow pan and adding the water. The pan is rotated and the lime is turned over and over and is thoroughly and evenly moistened. The amount of water used is carefully measured out so that there shall be just enough to satisfy the lime and produce a dry powder. The heat developed by the slaking drives off all superfluous water.

PROPERTIES OF LIME

9. The property of lime that makes it valuable in building work is the fact that it forms a paste, when slaked, that will harden upon exposure to the air and form a bond between bricks, stones, etc., and also a firm finish to a wall when plastered against lathing or masonry surfaces.

10. Slaking Lime.—Lime is slaked by spreading it over the bottom of a shallow wooden box or in a crater formed of sand, and moistening it with a suitable amount of water. High-calcium limes, which contain a large proportion of calcium oxide, have a great affinity for water and will absorb from one-quarter to one-third of their weight of water. They also act very vigorously when the water is applied. The lumps burst and crumble into powder, creating considerable heat and giving off vapor. This operation is called **slaking.** When high-calcium lime is slaked the powder formed has a bulk of from two to three times that of the original lump lime, one barrel of lump lime making two or three barrels of slaked lime.

Usually when lime is slaked, more water is added than is actually required merely to slake the lime and form a powder. This excess of water reduces the powder to a paste.

11. Fat, or rich, limes are limes rich in calcium oxide. They slake energetically and form an abundance of paste which has a soft, unctuous feeling. For this reason they are called *fat* limes. They are also sometimes called *quick* limes.

Meager, or poor, limes do not contain so much calcium oxide as rich limes; but they contain more silica, alumina, and iron oxides and do not therefore slake so violently as rich limes. They do not increase in bulk more than 50 to 100 per cent. These limes are sometimes called *slow* limes.

Magnesium limes also slake slowly and generate less heat than calcium limes and do not require so much water. When these limes contain silica, alumina, and iron oxide, the slaking is retarded as in the case of calcium limes.

12. In all limes it is the presence of calcium oxide that causes the slaking. The quickness of the slaking and the abundance and richness of the paste is in proportion to the amount of calcium oxide in the lime.

Fat limes produce a paste that has smooth working qualities and can carry a considerable quantity of sand. Poor limes make a smaller amount of paste which cannot carry much sand. These characteristics make meager limes unsatisfactory for use in building.

13. Burning and Drowning.—A quick lime requires a large volume of water, which should be supplied quickly and the lime should be turned over so as to be brought into contact with the water as soon as possible. If insufficient water is used parts of the lime become dry and are *burned*. Lime that has been burned does not work smoothly and is tough.

A slow lime does not require a great amount of water, and care should be taken that an excess of water is not used. Too much water makes the paste too thin and the lime is said to be *drowned*.

14. Air-Slaking.—Lime when exposed to a damp atmosphere, slowly absorbs moisture and the lime falls to a powder, increasing in bulk, but without developing perceptible heat. Lime slaked in this manner is said to be *air-slaked*. Such lime is deficient in hardening properties, and should not be employed for structural purposes.

15. Hardening of Lime.—Lime hardens by reason of the gradual absorption of carbon dioxide from the air, the carbon dioxide slowly changing the lime from the form of calcium hydrate to calcium carbonate, so that the final result is to restore the material to the condition in which it was before burning, hardened lime mortar being practically limestone containing sand. To secure this result, however, all parts of the mortar must be readily accessible to dry air. If placed in damp situations or under water, or if excluded from contact with the air, lime mortars will not harden. Even in the interior of thin building walls of brick laid in lime mortar, the lime will be soft, crumbly, and sometimes even plastic after several years, although the edges of the mortar, where exposed, are perfectly hard. It is chiefly for this reason that lime mortars are not employed in important work.

The common limes will not harden under water or in damp places excluded from contact with the air. In hardening, the lime paste shrinks to such an extent that it cannot be employed for mortar without a large percentage of sand. Slaked lime mixed into a paste may be kept for an indefinite time without deterioration, if protected from contact with the air. This is accomplished by covering the lime with the sand that is to be subsequently incorporated with it in making the mortar for which the lime is intended.

16. Popping or Pitting.—Popping or pitting occurs in walls that are plastered with mortar made with lime that has been slaked on the job. It is caused by unslaked particles of lime being incorporated in the finished plastering on the wall and afterward becoming wet, as when a water-color paint or a size containing water is applied to the wall. The particles then slake and expand with considerable force, pushing off small portions of the surface of the plastering. This is called *popping*. The wall will show a shallow hole or pit wherever *popping* has occurred, thus giving rise to the term *pitting*. This is disastrous to plastering work as well as to decorations that have been applied to the plaster. To prevent popping it is necessary carefully to strain all slaked lime through a fine sieve before incorporating it in the mortar, so that no unslaked particles will be mixed in with the plastering mortar.

17. Properties of Hydrated Lime.—The property that makes hydrated lime particularly valuable is that it is thoroughly slaked. It will keep indefinitely and is in a very convenient form for measuring, especially when it is to be used in connection with Portland cement.

MISCELLANEOUS DATA ON LIMES

18. Quick Lime.—The weight of lump lime is from 50 to 60 pounds per cubic foot. A bushel of lime weighs from 75 to 80 pounds. A bushel contains from 1 to 1⅓ cubic feet. Two and one-half bushels are considered as the equivalent of 1 barrel. The contents of a bushel vary with the state laws. A barrel of lump lime will weigh from 185 to 230 pounds. One barrel of fat lime will make about 2½ barrels or 8 cubic feet of stiff lime paste. A barrel of quick lime will require about 30 to 40 gallons of water to form a stiff paste.

19. Hydrated Lime.—Hydrated lime is packed in paper sacks containing 40 pounds and 50 pounds and in jute sacks containing 100 pounds. Hydrated lime weighs about 40 pounds per cubic foot. A 100-pound sack therefore contains about 2½ cubic feet. One cubic foot of hydrated lime produces about 9/10 cubic foot of paste and requires an equal weight of water, or about 5 gallons, to produce the paste.

CEMENTS

CLASSIFICATION OF CEMENTS

20. Cement may be divided into three general classes: *Portland, natural,* and *puzzolan* (also called *pozzuolana*). The relative importance of each cement is indicated by the order in which is it named.

These cements are all hydraulic, that is, they will set and harden under water. Of the three classes only two need be considered, namely, Portland and natural cements, as puzzolan cements are rarely if ever used in building operations in the United States or Canada.

21. Portland cement may be defined as the product resulting from the process of grinding an intimate mixture of calcareous (containing lime) and argillaceous (containing clay) materials, calcining (heating) the mixture until it starts to fuse, or melt, and grinding the resulting clinker to a fine powder. It must contain not less than 1.7 times as much lime by weight as it does of those materials which give the lime its hydraulic properties, and must contain no materials added after calcination, except small quantities of certain substances, not to exceed 3 per cent. of the volume of the cement, which are used to regulate the activity or the time of setting.

22. Natural cement is the product resulting from the burning and subsequent pulverization of an argillaceous limestone or other suitable rock in its natural condition, the heat of burning being insufficient to cause the material to start to melt

CEMENT MANUFACTURE

23. Portland Cement.—Portland cement is made from a great variety of materials, the most common combinations of ingredients used in the United States being argillaceous limestone and pure limestone; limestone and clay; marl or chalk and clay; and blast-furnace slag and limestone. After the separate ingredients have been subjected to chemical analysis and their composition determined, they are mixed in suitable proportions and ground together to an extremely fine powder. The powdered mixture is then burned in rotary kilns, which consist of long, slowly revolving, horizontal cylinders. The mixture is fed into one end of the kiln and passes slowly toward the other end, encountering a gradually increasing temperature until finally it is met by a blast of flame, which calcines the mixture and changes it into a clinker before it passes out of the kiln. The temperature of burning averages about 2,700° F.

The burned clinker is in the form of irregular round balls about the size of a walnut. This clinker has no properties of setting, and will not set when wet with water until after it has been ground. The clinkers are therefore ground into impalpable powder, so that all portions may be active. The customary method of specifying the fineness of the cement is that it shall leave a residue of not more than 8 per cent., by weight, on a No. 100 sieve, and not more than 25 per cent. on a No. 200 sieve. Cement made in this manner is usually extremely quick-setting and hardens so rapidly that it cannot be properly handled. To retard this activity not more than 3 per cent. of calcium sulphate (plaster of Paris, or gypsum) is mixed with the finished cement.

Cement made by this process from blast-furnace slag and limestone is considered to be a true Portland cement. If, however, the material is not burned, the product is classed as puzzolan.

The distinguishing characteristics of the manufacture of Portland cement are the use of a carefully proportioned mixture of suitable ingredients, the grinding before calcination, the calcination to incipient fusion, and a second grinding of the product of calcination to an impalpable powder.

24. Natural Cement.—Natural cement is made by the direct burning of an argillaceous limestone, without the admixture of any other substances. The rock is not ground before burning, but is fed into the kilns just as it comes from the quarry.

The process is characterized by the use of a single variety of material in its natural condition, the lack of grinding before burning, and the lower heat, about 1,500° F., employed, as compared with that required for Portland cement.

PROPERTIES OF CEMENTS

25. The cements used in building, such as Portland cement and natural cement, differ from the limes in that they do not slake after calcination, and that they set, or harden, under water. For this reason they are called hydraulic cements. They can be formed into a paste with water without any sensible increase in volume and with little, if any, disengagement of heat. They do not shrink appreciably in hardening, so that the sand with which they are mixed is employed merely through motives of economy and not, as with limes, of necessity.

26. Composition.—Hydraulic cements are composed essentially of silica, alumina, and lime, and also contain, in smaller quantities, iron oxide, magnesia, and sulphuric acid. In Portland cement, the active ingredients are certain silicates and aluminates of lime. The iron oxide acts similarly to the alumina, but is usually present in much smaller quantity. The gray color of cement is due to the presence of this iron, since the silicates and aluminates of lime are white. Magnesia acts as an adulterant, and, if present in excess of 4 or 5 per cent., may impart injurious properties to the material, especially if it is used in sea-water. The presence of sulphuric acid is principally due to the addition of calcium sulphate, which is employed to control the time of setting. Sulphuric acid is injurious if present in excess.

Table I shows the various chemical substances that occur in good Portland cement, also minimum and maximum percentages of each that are allowable.

27. Maturing of Cement.—When cement comes from the kiln, it sometimes contains free lime. If this cement is employed on any work, the lime will continue to slake after the cement is set, which will cause cracks in the work. Therefore, cement should be *seasoned,* that is, kept for some months before being used. This will give time for any free lime to air-slake and will thus avoid subsequent trouble.

28. Setting of Cement.—A very important consideration is the time required for cement to set. This depends on a great many conditions, such as the amount of water added to the dry cement, the temperature of the atmosphere, and various other things. If the minimum amount of water is added, Portland cement will have an initial set in 2 or 3 hours and a hard set in 6 or 8 hours. Natural cement, under the same conditions, will develop an initial set in from 20 to 30 minutes and a hard set in from 40 to 60 minutes.

TABLE I

COMPOSITION OF STANDARD PORTLAND CEMENT

Chemical Substance	Percentage Limits
Lime	60 to 65
Silica	20 to 24
Alumina	5 to 10
Iron-oxide	2 to 5
Magnesia	1 to 4
Sulphuric acid	.5 to 1.75

Cement has a tendency to get stronger and stronger for some time after it has set. It is a noticeable fact that cements that set very rapidly do not develop so much additional strength after the first month of set as do the slower-setting cements.

That cement should be put in place before it begins to set is very important. Some masons, however, have an idea that if they let the cement get an initial set and then add more water and remix it, or *retemper* it, as they say, a greater final strength will be developed than if used the proper way. This notion has been proved to be incorrect, and the practice should never be followed.

29. Various substances may be mixed with cement to make it set slowly. Among these is *sulphate of calcium* (plaster of Paris). The addition of 1 or 2 per cent. of this material will delay considerably the setting of cement. When cement is mixed with sand, it sets slower than does the neat (pure) cement.

30. Contraction of Cement.—When cements set in air, they contract; when they set in water, they expand. A neat cement mortar will contract more than one containing sand. At the end of 12 weeks the contraction of cement is never more than .03 of 1 per cent. In order to avoid cracks, on account of the contraction of cement when setting in air, the usual custom is to keep the work moist by constant sprinkling or by covering it with wet straw. In this way the mass can be made to set with but little contraction.

31. Neat cement, or cement without the addition of materials other than water, is seldom used except for special purposes. It is sometimes used as a waterproof coat for a concrete roof or in similar places. Although not absolutely waterproof, yet it is much more so than sand-cement mortar or cement concrete. On the whole, cement is generally used mixed with sand or with sand and broken stone.

32. Strength of Cement.—In Table II are given some figures showing the tensile strength of cement and cement mortars, the tensile strength being the strength which resists their being pulled apart. These values are not exceptional, but are those that should be obtained, with good materials, in everyday practice. No two samples will show the same strength but should not develop less strength than given in the table. The samples should be allowed to stand for 1 day in moist air and then be submerged in water for the remainder of the time of testing.

Several samples are made from the same lot of cement and some are tested after 24 hours, some after 7 days, and some after 28 days. The cement should be stronger at the end of 7 days than after 24 hours. It should also be stronger at the end of 28 days than after 7 days. If the samples indicate a decrease in strength the cement should not be used in building.

33. Color.—The color of the different grades of cement is variable, but in certain cases it is distinctive. Portland cement is a dark bluish gray; if it is a light yellow, it may indicate underburning. Natural cement ranges in color from a light straw, through the grays, to a chocolate brown. In general, however, the color of cement is no criterion of its quality, except when a certain brand shows a variation in color, thus indicating a lack of uniformity in the raw materials or in the process of manufacture.

TABLE II

STRENGTH OF AMERICAN PORTLAND CEMENT AND MORTAR

Mixture	Time Allowed to Set		Tensile Strength per Square Inch Pounds
	In Moist Air	In Water	
Neat cement	24 hours		150 to 200
Neat cement	1 day+	6 days	450 to 550
Neat cement	1 day+	27 days	550 to 650
1 part cement, 3 parts sand	1 day+	6 days	150 to 200
1 part cement, 3 parts sand	1 day+	27 days	200 to 300

34. Adaptability.—Portland cement is adaptable to any class of mortar or concrete construction, and is unquestionably the best material for all such purposes. Natural cements, however, are cheaper, and under certain conditions may be substituted for the more expensive Portland cement. All heavy construction, especially if exposed, all reinforced-concrete work, sidewalks, concrete blocks, foundations of buildings, piers, walls, abutments, etc., should be made with Portland cement.

35. Weight.—Cement is packed and sold in wooden barrels or in cloth or paper bags, the bags being the form of package most commonly employed. A barrel of Portland cement contains the equivalent of four bags, while but three bags of natural cement equals a barrel. The average weights of these cements are given in Table III.

A bag of cement really has a volume of about .9 cubic foot, but in actual work 1 bag of cement is often counted as 1 cubic foot.

TABLE III

AVERAGE WEIGHTS OF HYDRAULIC CEMENTS

Kind of Cement	Net Weight of Bag Pounds	Net Weight of Barrel Pounds	Weight per Cubic Foot Pounds	
			Packed	Loose
Portland	94	376	110	92
Natural	94	282	85	55

36. Requisites of Good Portland Cement.—Good Portland cement must possess the following characteristics according to the standard specifications of the American Society for Testing Materials:

1. *Color:* Dull bluish gray; any variation from this indicates some impurity.

2. *Fineness:* It must leave by weight a residue of not more than 8 per cent. on a No. 100 sieve, and 22 per cent. on a No. 200 sieve.

3. *Time of Setting:* It must develop the initial set in not less than 30 minutes, and the hard set in not less than 1 hour nor more than 10 hours.

4. *Specific Gravity:* When thoroughly dried at 212° F., the specific gravity must be not less than 3.10. In other words, a certain volume of cement should weigh 3.10 times as much as an equal volume of water.

5. *Tensile Strength:* Briquets 1 inch square in section must show the following minimum tensile strengths in pounds per square inch: Neat cement, 24 hours in moist air, 150 to 200; 7 days, 450 to 550; 28 days, 550 to 650; mortar composed of one part cement and three parts sand, 7 days, 150 to 200; 28 days, 200 to 300, as shown in Table II.

6. *Soundness:* Pats of neat cement about 3 inches in diameter and ½ inch thick at the center and tapering to a thin edge, kept (*a*) in moist air for 24 hours, (*b*) in air at normal temperature for 28 days, (*c*) in water at 70° F. for 28 days, and (*d*) in an atmosphere of steam above boiling water for 5 hours, must remain firm and hard and show no signs of distortion, checking, cracking, or disintegration.

7. The cement shall not contain more than 1.75 per cent. of anhydrous sulphuric acid, nor more than 4 per cent. of magnesia.

TESTING CEMENTS

37. Character of Tests.—The quality or constructive value of a cement is ascertained by submitting samples of the cement to a series of tests. The properties usually examined are *specific gravity, activity, soundness, fineness,* and *tensile strength.* Chemical analysis is sometimes made to detect adulterations and to ascertain if harmful constituents are present. As architects and contractors usually do not have the necessary appliances for making tests of cement, it is the custom to sample each lot of cement as it is delivered, and to send the samples to a testing laboratory to be tested.

38. Sampling.—The cement is sampled by taking a small quantity (1 to 2 pounds) from the center of the package. The number of packages sampled in any given lot depends on the kind of work, and varies from a sample from every package to one in five or one in ten. When the cement is packed in barrels, the sample is obtained by boring with an auger either into the head or into the center of the barrel, drawing out a sample, and then closing the hole with a piece of tin tacked firmly over it. For drawing out the sample, a brass tube sufficiently long to reach the bottom of the barrel is used. The tube is thrust into the barrel, turned around, and pulled out; the core of cement is then knocked out into the sample can, which is usually a tin box with a tightly fitting cover. When the cement is in bags, the sample is taken from the surface to the center. Each sample should have a label, stating the number of the sample, the number of bags or barrels it represents, the brand of the cement, the purpose for which it is to be used, and the date of delivery and that of sampling. The sample should be sent at once to the testing office, and none of the cement should be used until the report of the tests is received. The testing of cement ordinarily consumes 30 days; therefore, the supply must be gauged so that a sufficient quantity will be kept on hand to allow the tests to be made without delay to the work of construction. Sometimes a 7-day test is sufficient to determine the value of a cement, and will be more convenient and economical, although there is always a certain amount of risk. The strength to be expected of cement that has set for 7 days is given in Table II, which is in accordance with the best practice.

MISCELLANEOUS DATA

39. Packages, Etc.—All mills now pack Portland cement in standard cloth sacks or paper bags, containing 94 pounds, net weight, of cement. This amount is considered as 1 cubic foot when mixing with sand to make mortar, although it is only about .9 cubic foot in volume. Four of these sacks or bags make a barrel.

A carload of Portland cement varies from 400 to 600 sacks or bags.

Cloth sacks are billed to the cement purchaser at a fixed price for each. When empty they may be returned to the dealer or to the mill from which the cement was purchased and they will be bought back if they are in good condition and suitable for further use as cement containers. A cement sack that has been wet, torn, or otherwise rendered unfit for use, will not be redeemed.

In returning cloth sacks for redemption, railroad companies require that the sacks be bundled in a certain manner.

Cement mills also have regulations governing the return of sacks. Any railroad freight agent can inform a shipper as to how sacks must be bundled and marked to come within the requirements of railroad rules governing such shipments.

Although cement is sometimes packed in paper bags, this practice is not so general as the use of cloth sacks. The charge for paper bags is considerably less than for cloth ones, but the paper bags are not redeemable.

SAND

40. Definition of Sand.—Sand is an aggregation of loose, incoherent grains of crystalline structure, derived from the disintegration of rocks. It is obtained from the seashore, the banks and beds of rivers, and land deposits. The first class, called *sea sand,* contains alkaline salts that attract and retain moisture and cause efflorescence in brick masonry. The second, termed *river sand,* is generally composed of rounded particles, and may or may not contain clay or other impurities. The third, called *pit sand,* is usually composed of angular grains, and often contains clay and organic matter; when washed and screened, it furnishes a good sand for general purposes.

41. Uses of Sand.—The principal uses of sand are in making mortar for brick and stone masonry and for plastering, also in making concrete. Sand prevents excessive shrinkage and reduces the amount of lime or cement used. Lime adheres better to the particles of sand than to its own particles; hence, sand is considered as adding strength to lime mortar. On cement mortar, on the contrary, it has a weakening effect.

TESTING OF SAND

42. The quality of sand intended for use in mortar is ascertained by determinations of its weight, percentage of voids, form of grain, fineness, cleanness, and by strength tests of the actual mortar. For cement mortars and concretes, the character of the sand employed is most important, since it vitally affects the strength, density, and permanency of the finished structure.

43. Weight.—The weight of sand is determined by filling a cubic-foot measure with dried sand and obtaining its weight. Dry sand weighs from 90 to 106 pounds per cubic foot. A cubic yard of sand weighs from 2,400 to 2,800 pounds. The weight of sand is dependent on the size and shape of the sand grains, but, other things being equal, the heaviest sand makes the best mortar.

44. Percentage of Voids.—By **percentage of voids** is meant the amount of air space in the sand. Structurally, it is one of the most important properties of sand. The greater these voids, the more cement paste will be required to fill them in order to give a dense mortar; or, conversely, with a given proportion of cement and sand, the sand that has the smallest voids will produce the strongest, the densest, and the most impervious mortar.

The percentage of voids may be determined by observing the quantity of water that can be introduced into a vessel filled with sand.

The percentage of voids is dependent principally on the size and shape of the sand grains and the gradation of its fineness, and hence will vary from 25 to 50 per cent. Sand containing over 45 per cent. of voids should not be used to make mortars.

45. Shape of Sand Grains.—The shape of the grains of sand is of chief importance in the influence that the sand exerts on the percentage of voids. Obviously, a sand with rounded grains will compact into a more dense mass than one whose grains are angular or flat like particles of mica. Therefore, the more nearly the grains approach the spherical in shape, the more dense and strong will be the mortar. This fact must be carefully remembered, as it is contrary to the common opinion on the subject.

46. Fineness.—The fineness of sand is determined by passing a dried sample through a series of sieves having 10, 20, 30, 40, 50, 74, 100, and 200 meshes, respectively, to the linear inch. The result of this test, expressed in the amount of sand passing each sieve, is known as the **granulometric composition** of the sand. Material that does not pass a ¼-inch screen is not considered to be sand, and should be separated by screening. Sand that is practically all retained on a No. 30 sieve is called *coarse,* while 80 or 90 per cent. of sand known as *fine* will pass through this sieve. Fine sand produces a weaker mortar than coarse sand, but a mixture of fine and coarse sand will surpass either one.

47. Cleanness.—The cleanness of sand may be roughly ascertained by rubbing it between the fingers and observing how much dirt remains. To determine the percentage of the impurities more accurately, a small dried and weighed sample is placed in a vessel and stirred up with water. The sand is allowed to settle, the dirty water poured off, and the process repeated until the water pours off clear. The sand is then dried and weighed. The loss in weight gives the quantity of impurities contained in the sand. The presence of dirt, organic loam, mica, etc. is decidedly injurious and tends to weaken the resulting mortar. Clay or fine mineral matter in small proportions may actually result in increased strength, but excessive quantities of these materials may be a possible source of weakness. The best modern practice limits the quantity of impurities found by this washing test to 5 per cent.

PREPARATION OF SAND

48. Sand is prepared for use in making mortar by (1) screening, to remove the pebbles and coarser grains, the fineness of the meshes of the screen depending on the kind of work in which the sand is to be used; (2) washing, to remove salt, clay, and other foreign matter.

MORTARS

PROPORTIONS OF INGREDIENTS

49. Mortars for structural purposes are composed of lime or cement, or both, and sand mixed to the proper consistency with water. The proportions of the ingredients depend on the kind of work in which the mortar is to be used. The quality of the mortar depends on the quality of its constituents, the proportions in which they are combined, and the methods by which they are mixed and used.

In proportioning mortar, it is customary to designate the quantities of the separate ingredients by a ratio, such as 1–1, 1–2, 1–3, etc. Thus, 1–1 signifies that the mortar is composed of 1 part of lime or cement to 1 part of sand; 1–2, that 1 part of lime or cement is used to 2 parts of sand; etc. These measurements are usually made by volume instead of by weight. The first number of the ratio always indicates the quantity of lime or cement, which, for convenience, is taken as the unit of volume.

LIME MORTARS

50. Ingredients.—When a mortar is made of lime and sand, enough lime should be present to just cover completely each grain of sand. An excess of lime over this quantity causes the mortar to shrink on drying, while a deficiency of lime produces a weak and crumbly mortar. The correct quantity of lime depends on the character of the ingredients, the method of treatment, and, to some extent, on the judgment of the builder, the mixtures employed varying from 1–2½ to 1–5. Building laws in many muncipalities require the use of a 1–3, or a 1–4, mixture, and for most materials this proportion will be found satisfactory.

51. Mixing.—In mixing lime mortar the first process is to slake the lime. The lime is spread over the bottom of a shallow, water-tight box made of wood or sheet iron. Water is then run into this box through a hose until there is enough to slake all the lime and to form a paste. The lumps of lime are stirred around with a hoe when it is necessary to bring them in contact with the water. When the entire batch of lime has been slaked it is allowed to run out of the box through a fine wire screen, which keeps the dirt and unslaked particles from running out. The lime is caught in another box and is covered with a quantity of sand and is allowed to stand until the second batch is to be slaked, when it is shoveled out into a pile, where it should remain for several days so that any particles that may not have thoroughly slaked may be slaked.

52. When mortar is required at the building, the lime and sand which has been piled up is mixed with more sand and the mass is worked with the hoe until it is thoroughly mixed and shows a uniform color. The mixture is then suitable for use as mortar and is shoveled into hods or wheelbarrows and carried to the mortar boards where the masons are at work.

The mixing of mortar, especially lime mortar or lime-cement mortar, requires considerable experience on the part of the mixer, who judges whether the mortar has too little or too much sand in it by the action of the mortar when it is being hoed.

If when the ingredients are thoroughly mixed, the mortar tends to stick to the blade of the hoe when the blade is raised to a vertical position, more sand should be added. If the mortar slides from the blade of the hoe too freely, there is too much sand in the mixture. The same test can be made by the mason who uses the mortar, by observing the action of the mortar when manipulated by a trowel. The mortar should be smooth or rich, but at the same time should neither stick to the trowel nor drop off the trowel too freely.

Thus, the best proportions of lime and sand to use are best determined while mixing the mortar. The *richer,* or *fatter,* the lime the more sand it will carry.

A mortar that drops off the hoe or trowel too readily is called *short;* and is hard to manipulate and will not adhere properly to the masonry. The addition of a small amount of lime paste or hydrated lime to a cement mortar will prevent its being short; about 5 to 15 per cent. of the volume of the cement should be sufficient.

53. It is good practice to slake all the lime that will be required for a job of masonry several days before it will be used, as this method gives small unslaked particles that may have come through the strainer a chance to slake before they are placed in the wall.

54. Careful slaking is imperative in mixing plastering mortar where such mortar is made from slaked lime, although this precaution is less and less necessary, as patent plasters are almost universally employed. These plasters are of the nature of cements, and set instead of drying out.

55. Use of Lime Mortar.—Lime mortar is not used in the best work, as it is absolutely unsuitable for any important construction, because it possesses neither strength nor the property of resisting water. It should not be used in damp or wet situations, and should not be laid in cold weather, as it is very susceptible to the action of frost. It is used mostly in cheap work, as mortar for rubble masonry and brickwork, on account of its low cost.

56. Strength of Lime Mortars.—The strength of lime mortars is extremely variable, depending on the ingredients themselves and on their treatment, environment, etc. Moreover, it is unsafe to figure a lime-mortar joint as possessing much strength, since only a part of the joint is hardened and capable of developing any strength at all. The tensile strength of thoroughly hardened 1–3 lime mortars averages from 40 to 70 pounds per square inch, and the compressive strength, or resistance to crushing, from 150 to 300 pounds per square inch.

CEMENT MORTARS

57. Ingredients.—**Cement mortars** consist of cement, sand, and water, and the character and proportions of these ingredients vitally affect the properties of the resulting product. As has been stated, the cement for all structures of importance should be Portland, although natural cement may occasionally be employed to advantage where the conditions permit.

58. The sand for all mortars should be clean and of suitable granulometric composition. For structures designed to withstand heavy unit stresses, or for those intended to resist either the penetration of moisture or the actual pressure of water, the selection of the sand should be most carefully made. Generally, it is not advisable to use a sand containing over 5 per cent. of loam by the washing test, nor one that soils the fingers when it is rubbed between them. These points should be especially considered when the sand is to be used for mortars intended for facing, pointing, or waterproofing. Moreover, for most classes of work, the preference should usually be given to a rather coarse sand, although sand containing all sizes of grains, from coarse to fine, more nearly approaches the ideal in producing the densest and strongest mortar. Very fine sand, such as is found on the seashore, should not be employed in mortar unless it is intended simply for pointing or for grouting.

A simple method of determining the best sand for cement mortar is to prepare mixtures of the cement, sand, and water, using the same quantities in each case, and then to place each mixture in a measure; that mixture giving the least volume of mortar may be considered to contain the most desirable sand for use.

59. The water used in mixing cement mortar should be clean, fresh, and free from dirt or vegetable matter. Water containing even small quantities of acid may seriously injure the mortar. The presence of oil will result in slow setting and decreased strength. Salt water may be used if necessary, but it also retards the setting, and decreases the strength.

60. Proportion of Ingredients.—The theory of the composition of a correctly proportioned mortar is that the cement paste will just a little more than fill all the voids between the particles of sand, thus giving an absolutely dense mortar at the least expense. If more cement is used, the cost will be increased, while less cement will result in a weaker and porous mortar. The correct proportion of cement to sand, therefore, is more or less variable, depending on the granulometric composition of the sand. Experience and tests have shown that 1-3 mixtures most nearly approach the best and most economical proportion. This mixture is in fact most generally employed for mortars used in buildings, walls, etc. and is the proportion commonly specified by corporations and municipalities for such work.

61. Mortars, however, are made in proportions varying from 1-1 to 1-6. The richer mixtures are used for facing, pointing, waterproofing, etc., the 1-2 mixture being usually made for such purposes. The leaner mixtures are used for rough work, filling, backing, etc., but should never be employed where either much strength or much density is desired. Natural-cement mortars are commonly made with 1 part of sand less than Portland-cement mortars intended for the same purpose; that is, where a 1-3 Portland-cement mortar would be used, a 1-2 natural mortar would be used, although natural-cement mortars should be decreased by about 2 parts of sand to equal the strength of Portland. In other words, a 1-4 Portland mortar closely equals the strength of a 1-2 natural mortar.

62. Measurement of Ingredients.—Cements are commonly proportioned by volume, the unit volume of the cement barrel being assumed. Various values for this unit volume are taken by different authorities, but the general practice is to assume that the Portland-cement barrel contains 3.6 cubic feet, and that the bag contains .9 cubic foot. If a 1-3 mortar is desired, a box having a capacity of 10.8 cubic feet is filled with sand and mixed with 4 bags or 1 barrel of cement. A box 3 feet 3½ inches square and 1 foot deep will have a capacity of very nearly 10.8 cubic feet and besides makes a convenient size of box for measuring the sand.

63. Quantity of Water.—The quantity of water required varies with the richness of the mixture and the character of the ingredients, so that it is difficult, if not impossible, to state just how much should be used at all times. For general purposes, the mortar should be of a plastic consistency—firm enough to stand at a considerable angle, yet soft enough to work easily.

64. Quantities of Materials Required for Mortar. In Table IV are given the quantities of materials required to produce 1 cubic yard of compacted mortar. The proportions are by volume, a cement barrel being assumed to contain 3.6 cubic feet. Of course, the quantity of mortar produced from any mixture of materials will vary with the character of the ingredients, but the data given in the table will serve as a guide for the quantities required under average conditions.

TABLE IV

APPROXIMATE AMOUNTS OF MATERIALS FOR 1 CUBIC YARD OF CEMENT MORTAR

Mixture	Portland Cement			Sand		
	Barrels		Bags	Cubic Yard		Tons
1–1	4¼	or	17	⅝	or	¾
1–2	3	or	12	¾	or	1
1–3	2¼	or	9	⅞	or	1
1–4	1¾	or	7	1	or	1¼
1–5	1⅜	or	5½	1	or	1¼
1–6	1¼	or	5	1	or	1¼

EXAMPLE.—How much cement and sand will be required to make 8½ cubic yards of 1–3 Portland-cement mortar?

SOLUTION.—According to Table IV, 1 cu. yd. of a 1–3 Portland-cement mortar will require 2¼ bbl. or 9 bags of cement; therefore, 8½ cu. yd. will require 8½×2¼=19⅛ bbl. or 8½×9=76½ bags of cement. One cu. yd. of mortar will require ⅞ cu. yd. or 1 T. of sand; therefore, 8½ cu. yd. will require 8½×⅞=$7\frac{7}{16}$ cu. yd. or 8½×1=8½ T. of sand. The amounts of material that will be required are

Portland cement, 19⅛ bbl. or 76½ bags }
Sand, $7\frac{7}{16}$ cu. yd. or 8½ T. } Ans.

65. Mixing.—It is essential in making cement mortars to secure a complete and uniform mixture of the various ingredients. This kind of a mixture is of course best obtained by means of mechanical contrivances; but since mechanical mixers are expensive to install and operate, it is only on extensive works, where large quantities of material can be used in a short time, that such appliances can be employed to advantage.

66. Mortar that is to be mixed by hand is prepared on a platform or in a mortar box. The sand is first measured by means of a bottomless barrel, or, better, by means of a low, square, bottomless box with handles on the sides and of such a size that it will give the correct proportion of sand. After filling the box, the sand is struck off level, the box lifted up, and the sand spread in a low, flat pile. The required number of bags of cement are then emptied on the sand and spread evenly over it. The pile is then turned over and mixed with shovels, working through it not less than four times. After this operation, the dry mixture is formed into a ring, or crater, and the water intended to be used is poured into the center. The material from the sides of the basin is then shoveled into the center until the water is entirely absorbed, after which the pile is worked again with shovels and hoes until the mixture is uniform and in a plastic condition. In mixing, the mortar should be completely turned over not less than four times dry and from four to six times after the water has been added.

67. Another method of mixing, where a mortar box is used, is to gather the mixed dry materials at the upper end of the tilted box and pour in the water at the other end, then to draw the mixture into the water with a hoe a little at a time, and to hoe until a plastic consistency is obtained.

A method that is sometimes used in measuring out the ingredients of the mortar when it is necessary to save time, is to place 2 cubic feet of sand into a wheelbarrow and carefully note the space that it occupies in the barrow. The sand can then be measured by filling the barrow with sand to the same extent each time and dumping the contents on the mixing platform, such a quantity being considered as 2 parts of sand for 1 bag of cement. This method is a good one if conscientiously carried out. The man shoveling the sand into the wheelbarrow may be careless and add two or three shovelfuls of sand to each barrow, thus changing the mixture and weakening it. Careful superintendence, however, will check this tendency.

68. Good results can be secured by any of these methods, provided sufficient care is exercised. If a batch of mortar is once made too wet, it cannot be brought back properly to a drier consistency; also, an excessively wet mortar is difficult to work and is often productive of poor results. The best plan, therefore, in adding the water is to pour in first a little less than is required and then make up the deficiency by means of a pail or a sprinkling hose. In this way, an excess of water is guarded against.

PROPERTIES OF CEMENT MORTARS

69. Strength.—In practice the strength of mortar is commonly determined through its resistance to tensile forces.

The tensile strength of mortar varies with the character of its ingredients, with its consistency, its age, and with many other factors. In Table V is given a fair average of the tensile strength that may be expected from mortars of Portland and natural cements that are made in actual practice and with a sand of fair quality but not especially prepared.

The strength of Portland-cement mortar increases up to about 3 months; after that period, it remains practically constant for an indefinite time. Natural-cement mortar, on the other hand, continues to increase in strength for 2 or 3 years, its ultimate strength being about 25 per cent. in excess of that attained in 3 months.

70. Adhesiveness.—The adhesion of mortars to inert materials varies both with the character of the mortar and with the roughness and porosity of the surfaces with which they are in contact. The adhesion of 1–2 Portland-cement mortar, 28 days old, to sandstone averages about 100 pounds per square inch; to limestone, 75 pounds; to brick, 60 pounds; to glass, 50 pounds; and to iron or steel, 75 to 125 pounds. In other words, it will require these forces to pull away the mortar from 1 square inch of the surface of the materials named.

71. Retempering.—Sometimes, during building operations, more mortar is mixed than is required for immediate use, and for this or some other reason batches of it are allowed to stand. In such cases, mortar composed of cement, sand, and water soon begins to set and tends to become hard. Then, when it is desired to use this material, more water is added and the mixture is worked until it again becomes plastic. This process is called **retempering.** Laboratory tests generally show that retempering slightly increases the tensile strength of mortar, but the reworking is more thorough as a rule in the laboratory than would be the case in actual work. Any part of the hardened mortar that is not retempered is a source of weakness when incorporated in the building. The adhesive strength of cement, moreover, is greatly diminished by this process. For these reasons, it is generally inadvisable to permit the use of retempered mortars. Architects generally specify that cement mortar shall not be used if retempered.

TABLE V

TENSILE STRENGTH OF CEMENT MORTARS

Proportions		Tensile Strength, in Pounds per Square Inch					
		Portland Cement			Natural Cement		
Cement Parts	Sand Parts	7 Days	28 Days	3 Months	7 Days	28 Days	3 Months
1	1	450	600	610	160	245	280
1	2	280	380	395	115	175	215
1	3	170	245	280	85	130	165
1	4	125	180	220	60	100	135
1	5	80	140	175	40	75	110
1	6	50	115	145	25	60	90
1	7	30	95	120	15	50	75
1	8	20	70	100	10	45	65

72. Laying Mortar in Freezing Weather.—Frost or even cold has a tendency to retard greatly the set of cement mortars. When the temperature, moreover, is so low that the water with which the mortar is mixed freezes before it combines with the cement, it may, if care is not exercised, result in complete destruction of the work. A single freezing is not particularly harmful, because when thawing occurs, the arrested chemical action continues. A succession of alternate freezings and thawings, however, is extremely injurious. Nevertheless, Portland-cement mortars may be laid even under the worst conditions if certain precautions are observed, but mortars of natural cement should never be used in extremely cold weather as they are generally completely ruined by freezing.

The bad results that arise during mild frost may be successfully guarded against by heating the sand and water and by using a quick-setting cement mixed rich and as dry as possible. Salamanders containing burning coke may also be placed on the scaffold to help to keep the brick and mortar warm. A salamander is a large cylinder of sheet iron supported on iron legs and having a sliding door near the bottom to allow of a draft. The fire is built in the cylinder. The finished work should also be protected with canvas. Unless the conditions are such as to make it imperative, it is not advisable to lay mortars during freezing weather.

73. Shrinkage.—Cement mixtures exposed to the air shrink somewhat during the process of hardening, while those immersed in water tend to expand. The shrinkage of ordinary cement mortars is slight, and when they are used as bonding materials it need not be considered.

74. Lime-Cement Mortars.—In brick work and in other work in which mortar is employed, it is frequently desired to use a material that is more plastic or smoother than pure cement mortar. This quality is usually obtained by adding to the mortar a quantity of hydrated lime equal to from 5 to 15 per cent. of the volume of the Portland cement in the mortar. This addition of lime not only renders the mortar more plastic, and hence easier to work, but also increases both its adhesive strength and its density, which assists in making the mortar waterproof. The term *lime-cement mortar,* however, generally refers to a mixture consisting of equal parts of cement and lime, either in the form of hydrated lime or lime paste mixed with sand. This is a very satisfactory mortar where great strength is not required and it is necessary to economize. A good formula for a lime-cement mortar is 1 part Portland cement, 1 part hydrated lime, and 6 parts clean sand by volume. This makes a strong and economical mortar.

If slaked lime is used instead of hydrated lime great care should be taken that the lime is thoroughly slaked, for any unslaked particles may, through their expansion, ultimately cause disintegration of the mortar. For this reason, hydrated lime is to be preferred for use in cement mortar, because its complete slaking is assured. Hydrated lime may also be more readily handled and measured on the work.

When lime paste is used, the lime is first mixed with the sand and the dry cement is added to the mixture as required, only such a quantity being mixed as can be used before the cement obtains its initial set.

WATERPROOFING OF MORTARS

75. Methods of Waterproofing.—All cement mortars to a greater or less degree absorb water. They therefore not only permit dampness to penetrate a building, but tend also to permit of destruction by frost. Cement mortars may be made almost impermeable by using only sand that has been carefully graded and by adding hydrated lime.

The proper proportion of hydrated lime to produce the best results in making mortar waterproof is from 5 to 10 per cent. of the amount of cement used. The smaller quantity of hydrated lime should be used for a rich mixture of cement and sand, such as 1–2, and the larger quantity for a mixture of 1–3. In a mixture of 1–4, a quantity of hydrated lime equal to 15 per cent. of the cement may be used.

Experiments seem to show that lime paste does not have the same quality of making the mortar waterproof that is possessed by hydrated lime.

Cement mortars can also be made impermeable by mixing patented compounds with them as directed by the manufacturers of the compounds.

COLORING OF MORTARS

76. Methods and Materials.—Colors are often used in mortars to effect contrasts, or to subdue the glaring tone of cement in sidewalks or in similar situations. For sidewalks, lampblack is commonly employed, 1 or 2 per cent. changing the color of cement to gray, or slate. In order to produce architectural effects, colors consisting of various mineral substances are added to the mortar in proportion of from 1 to 10 per cent. The color of hardened mortar is quite different in appearance from one that is still wet, so that where it is important to secure the correct tints, preliminary trials should be made until the proportions desired have been determined.

The various materials employed to produce different colors in mortar, together with the quantity required per barrel of cement, are as follows: For gray, 2 pounds of lampblack; for black, 45 pounds of manganese dioxide; for blue, 19 pounds of ultramarine; for red, 22 pounds of iron oxide; for bright red, 22 pounds of Pompeian or English red; and for violet, 22 pounds of violet oxide of iron. In practice, however, reliable brands of manufactured mortar colors or stains are used.

When white mortars are desired they are made with white sand and a large proportion of hydrated lime together with standard white Portland cement. White cements are made and when used with white sand make a perfectly white mortar. In making white mortar marble dust may be used instead of sand.

GROUTING AND POINTING

77. Grouting.—By *grouting* is meant the process of filling spaces in masonry with a thin, semifluid mixture known as *grout.* This mixture consists of cement, 1 or 2 parts of sand, and an excess of water. In fact, it can be used in all places where it is impracticable to lay mortar in the ordinary manner. When hardened, grout is weak, friable, and porous; therefore, it should not be employed if it can be avoided.

78. Pointing.—In the process known as *pointing,* finished joints of mortar are formed in masonry. Walls finished in this manner have not only a better appearance, but they are protected from injury by frost, as no water can accumulate in the joints. In pointing, the joints are raked out about three-fourths of an inch from the face of the wall and the pointing material introduced. An excellent pointing mortar is made of white Portland cement mixed with 1 or 2 parts of very fine sand. The addition of a little lime to the mortar also makes it waterproof, more adhesive, and easier to work. Pointing should never be attempted in freezing weather.

In pointing face stonework ordinary cement mortar is not generally used, as it stains and discolors many kinds of stone. A white Portland cement is manufactured which is used instead of the gray cement for this work, or Lafarge cement is used. Lafarge cement is a patented cement made in France.

QUANTITY OF MORTAR REQUIRED

79. The quantities of mortar required for masonry of various kinds are shown in Table VI. These quantities are approximate only, as different workmen use different quantities of mortar for the same kind of work, some flushing or filling the joints full of mortar and others putting in as little as the masonry will stand. The amounts shown in the table are those required for good work with the joints well filled.

80. The method of calculating the amounts of mortar required from the values given in Table VI is illustrated in the following examples:

EXAMPLE 1.—What is the maximum amount of mortar that will be required to build a brick wall, of ordinary brickwork, having joints $\frac{3}{8}$ inch in width, the wall being 40 feet long, 8 feet high, and 1 foot thick?

Solution.—The volume of the wall will be 40×8×1=320 cu. ft. According to Table VI the maximum percentage of the volume of the wall that will be occupied by the mortar is 30 per cent.

320×.30=96 cu. ft., or 96÷27=3.56 cu. yd. Ans.

Example 2.—What is the least amount of mortar that will be required to lay up a 4-inch facing of pressed brick 40 ft.×8 ft. and one brick thick with ⅛-inch joints?

TABLE VI

PROPORTION OF MORTAR IN MASONRY

Kind of Masonry	Amount of Mortar, in Percentage of Volume of Wall	
	Minimum	Maximum
Brickwork, coarse, ½-in. to ⅝-in. joints	35	40
Brickwork, ordinary, ¼-in. to ⅜-in. joints	20	30
Brickwork, pressed, ⅛-in. joints	10	15
Ashlar {Courses, 12 in. to 20 in. high Joints, ⅜ in. to ½ in.	7	8
Ashlar {Courses, 20 in. to 32 in. high Joints, ½ in. to ⅜ in.	5	6
Rubble, coarse, not dressed	33	40
Rubble, roughly dressed	25	30
Rubble, well-dressed, coursed	15	20

Solution.—The volume of the face brick will be 40 ft.×8 ft.×⅓ ft. =107 cu. ft. The minimum percentage of the volume of the wall occupied by the mortar, according to Table VI, is 10 per cent.

107×.10=10.7 cu. ft., or 10.7÷27=.4 cu. yd. Ans.

QUANTITIES OF MATERIALS REQUIRED FOR MORTARS

81. In Table IV the quantities of cement and sand necessary to make a cubic yard of cement mortar have been given. In Table VII are given the approximate amounts of materials required to make 1 cubic yard of cement mortars that contain amounts of hydrated lime equal to 5 per cent., 10 per cent., and 15 per cent. of the volume of the cement. These quantities are only approximate on account of variations in the amount of voids in the sand.

The following example shows the method of using Table VII:

Example.—It will require 4 cubic yards of mortar to lay up a certain wall. The mortar is specified to be 1–4 cement mortar containing hydrated lime to the amount of 10 per cent. of the volume of the Portland cement. How much cement, sand, and hydrated lime will be required for the work?

Solution.—Table VII shows that 1 cu. yd. of the mortar specified will require 6⅜ bags of cement, 1¼ T. of sand, and ⅔ bag of lime. Then, 4 cu. yd. will require 4×6⅜=25½ bags of cement, 4×1¼=5 T. of sand, and 4×⅔=2⅔ bags of lime.

TABLE VII

APPROXIMATE AMOUNTS OF MATERIALS REQUIRED TO MAKE 1 CUBIC YARD OF CEMENT MORTAR WITH HYDRATED LIME

Proportions of Materials			Materials Required to Make 1 Cubic Yard		
Cement Parts	Sand Parts	Hydrated Lime Per Cent. of Volume of Cement	Portland Cement Bags of 94 Pounds	Sand Tons	Hydrated Lime Bags of 40 Pounds
1	1	5	16	¾	1
1	2	5	11⅓	1	⅔
1	3	5	8½	1	½
1	4	5	6⅔	1¼	⅓
1	1	10	15½	¾	1½
1	2	10	10⅞	1	1⅛
1	3	10	8⅛	1	⅞
1	4	10	6⅜	1¼	⅔
1	1	15	14¾	¾	2¼
1	2	15	10½	1	1½
1	3	15	7	1	1
1	4	15	6	1¼	1

82. Table VIII gives the approximate quantities of materials required to make a cement-lime mortar containing hydrated lime and cement in equal parts. The materials are proportioned by volume and one 40-pound bag of hydrated lime will make about the same amount of paste as one 94-pound bag of cement. Its use is illustrated in the following example:

TABLE VIII

AMOUNTS OF MATERIALS REQUIRED FOR 1 CUBIC YARD OF CEMENT-LIME MORTAR

Proportions of Materials			Portland Cement Bags of 94 Pounds	Hydrated Lime Bags of 40 Pounds	Sand	
Cement Parts	Hydrated Lime Parts	Sand Parts			Cubic Yard	Tons
1	1	4	$5\frac{1}{2}$	$5\frac{1}{2}$	$\frac{3}{4}$ or	1
1	1	5	$4\frac{2}{3}$	$4\frac{2}{3}$	$\frac{4}{5}$ or	1
1	1	6	4	4	$\frac{4}{5}$ or	1
1	1	7	$3\frac{1}{2}$	$3\frac{1}{2}$	$\frac{7}{8}$ or	$1\frac{1}{8}$
1	1	8	$3\frac{1}{4}$	$3\frac{1}{4}$	$\frac{7}{8}$ or	$1\frac{1}{8}$

EXAMPLE.—A wall will require 3 cubic yards of 1-1-8 cement-lime mortar. How much cement, hydrated lime, and sand will be required to make that amount of mortar?

SOLUTION.—One cu. yd. of mortar of the proportions 1-1-8 will require $3\frac{1}{4}$ bags of cement, $3\frac{1}{4}$ bags of hydrated lime, and $1\frac{1}{8}$ T. of sand. Three cu. yd. will therefore require

$$\left.\begin{array}{l}3\times3\frac{1}{4}=9\frac{3}{4}\text{ bags cement}\\3\times3\frac{1}{4}=9\frac{3}{4}\text{ bags hydrated lime}\\3\times1\frac{1}{8}=3\frac{3}{8}\text{ T. sand}\end{array}\right\}\text{Ans.}$$

83. Amounts of Materials in Mortar for 1,000 Bricks.—In Table IX are given the approximate amounts of cement, hydrated lime, and sand that will be required for laying 1,000 of brick with mortar containing different proportions of materials. In this table the amounts of hydrated lime given are 5 per cent., 10 per cent., and 15 per cent. of the volume of the cement. The proportions make a strong and water-resisting mortar. The amount of mortar required will naturally vary according to the thickness of the joint, and the table shows the

TABLE IX

AMOUNT OF CEMENT MORTAR REQUIRED FOR 1,000 COMMON BRICK. SIZE OF BRICK 8¼ IN. × 4 IN. × 2¼ IN.

Size of Joint. Inches	Composition of Mortar			Materials Required			Size of Joint. Inches	Composition of Mortar			Materials Required		
	Cement	Hydrated Lime	Sand	Cement. Bags of 94 Pounds	Hydrated Lime Bags of 40 Pounds	Sand. Tons		Cement	Hydrated Lime	Sand	Cement. Bags of 94 Pounds	Hydrated Lime Bags of 40 Pounds	Sand. Tons
¼	I	5%	I	6⅜	⅜	⅓	½	I	5%	I	12¾	¾	⅝
¼	I	5%	2	4½	¼	⅜	½	I	5%	2	9⅛	½	⅞
¼	I	5%	3	3⅜	¼	⅜	½	I	5%	3	6¾	⅜	⅞
¼	I	5%	4	2⅝	⅛	½	½	I	5%	4	5⅓	¼	I
¼	I	10%	I	6¼	⅝	⅓	½	I	10%	I	12⅜	I¼	⅝
¼	I	10%	2	4⅜	½	⅜	½	I	10%	2	8¾	⅞	⅞
¼	I	10%	3	3¼	⅜	⅜	½	I	10%	3	6½	¾	⅞
¼	I	10%	4	2½	¼	½	½	I	10%	4	5⅛	½	I
¼	I	15%	I	6	⅞	⅓	½	I	15%	I	II¾	I¾	⅝
¼	I	15%	2	4¼	⅝	⅜	½	I	15%	2	8⅜	I¼	⅞
¼	I	15%	3	2¾	½	⅜	½	I	15%	3	5⅜	I	⅞
¼	I	15%	4	2⅜	⅜	½	½	I	15%	4	4¾	¾	I
⅜	I	5%	I	8	½	⅜	⅝	I	5%	I	14⅜	⅞	¾
⅜	I	5%	2	5⅝	⅓	½	⅝	I	5%	2	10¼	⅝	I
⅜	I	5%	3	4¼	¼	½	⅝	I	5%	3	7⅝	½	I
⅜	I	5%	4	3⅓	⅛	⅝	⅝	I	5%	4	6	⅓	I⅛
⅜	I	10%	I	7¾	¾	⅜	⅝	I	10%	I	14	I⅜	¾
⅜	I	10%	2	5½	⅝	½	⅝	I	10%	2	9¾	I	I
⅜	I	10%	3	4⅛	½	½	⅝	I	10%	3	7⅜	¾	I
⅜	I	10%	4	3¼	⅜	⅝	⅝	I	10%	4	5¾	⅝	I⅛
⅜	I	15%	I	7⅜	I⅛	⅜	⅝	I	15%	I	13¼	2	¾
⅜	I	15%	2	5¼	¾	½	⅝	I	15%	2	9½	I⅜	I
⅜	I	15%	3	3⅜	⅝	½	⅝	I	15%	3	6⅛	I⅛	I
⅜	I	15%	4	3	½	⅝	⅝	I	15%	4	5⅜	⅞	I⅛

proportions and amounts of materials for four sizes of joints. An example of the use of the table follows:

Example.—A building is to be built that will require 50,000 common brick which are to be laid with a ¼-inch joint. The specifications call for a 1–3 cement mortar that is to contain an amount of hydrated lime equal to 10 per cent. of the volume of the cement used. How much cement, lime, and sand will be required?

Solution.—In Table IX, under ¼-in. joint and 10-per-cent. lime, is found the mixture 1 part cement, 10-per-cent. lime, and 3 parts sand, which is the mortar specified. In the same line, under the heading Materials Required, will be found the amounts of materials required by the specified conditions for 1,000 brick. For 50,000 brick 50 times these amounts will be required, or

$$\left.\begin{array}{l} 3\tfrac{1}{4} \text{ bags} \times 50 = 162\tfrac{1}{2} \text{ bags cement} \\ \tfrac{3}{8} \text{ bag} \times 50 = 18\tfrac{3}{4} \text{ bags hydrated lime} \\ \tfrac{3}{8} \text{ T.} \times 50 = 18\tfrac{3}{4} \text{ T. sand} \end{array}\right\} \text{Ans.}$$

84. Table X gives the amounts of materials required to make sufficient cement-lime mortar, containing varying amounts of sand, for 1,000 common brick.

TABLE X

AMOUNT OF LIME-CEMENT MORTAR REQUIRED FOR 1,000 COMMON BRICK. SIZE OF BRICK 8¼ IN. × 4 IN. × 2¼ IN.

Size of Joint. Inches	Composition of Mortar			Materials Required			Size of Joint. Inches	Composition of Mortar			Materials Required		
	Cement	Hydrated Lime	Sand	Cement. Bags of 94 Pounds	Hydrated Lime Bags of 40 Pounds	Sand. Tons		Cement	Hydrated Lime	Sand	Cement. Bags of 94 Pounds	Hydrated Lime Bags of 40 Pounds	Sand. Tons
¼	1	1	4	2¼	2¼	⅜	½	1	1	4	4⅜	4⅜	⅞
¼	1	1	5	1⅞	1⅞	⅜	½	1	1	5	3¾	3¾	⅞
¼	1	1	6	1⅝	1⅝	⅜	½	1	1	6	3¼	3¼	⅞
¼	1	1	7	1⅜	1⅜	½	½	1	1	7	2¾	2¾	1
¼	1	1	8	1⅓	1⅓	½	½	1	1	8	2⅝	2⅝	1
⅜	1	1	4	2¾	2¾	½	⅝	1	1	4	5	5	1
⅜	1	1	5	2⅓	2⅓	½	⅝	1	1	5	4¼	4¼	1
⅜	1	1	6	2	2	½	⅝	1	1	6	3⅝	3⅝	1
⅜	1	1	7	1¾	1¾	⅝	⅝	1	1	7	3⅛	3⅛	1
⅜	1	1	8	1⅝	1⅝	⅝	⅝	1	1	8	2⅞	2⅞	1

EXCAVATING, SHORING, AND PILING

EXCAVATING

GENERAL

1. When the site of the building has been cleared of old buildings, trees, brush, boulders, and all other superfluous objects, and the lines of the excavation have been carefully laid out, the excavation proper may be commenced.

2. Stripping Sod.—If the site is covered with grass of good quality so that the sod can be used in the final grading of the grounds, the sod should be cut into strips and rolled up with the grass inside and stacked in a convenient place. The sod should be cut over the entire area of the excavation and for a distance of about 6 feet outside all around.

3. Loam.—The upper layer of soil, or the *top soil,* if it consists of good loam, should also be carefully removed and piled in a convenient place so that it can be used to finish off the grading where grass and flowers are to be planted.

4. Sand and Gravel.—If quantities of good sand and gravel are found when excavating, and they are suitable for use in making mortar or concrete, they should be piled where they will be convenient for use.

5. Rock.—Where rock is encountered in the excavation and is of such a character as to be useful in building the founda-

COPYRIGHTED BY INTERNATIONAL TEXTBOOK COMPANY. ALL RIGHTS RESERVED

tion walls, it should be broken up and piled where it can be easily reached when building the wall. It can sometimes be left in the bottom of the excavation where it will be handy for placing in the wall.

EXCAVATING SOILS OTHER THAN ROCK

6. Loosening the Soil.—Sand, loam, and clay can sometimes be excavated directly with shovels without being specially loosened. Where the soils are hard, however, or where they contain numerous stones, it becomes necessary to use picks, plows, or steam shovels to loosen them before they can be put into carts or wagons and hauled away.

In small excavations, picks are usually employed. Where the area to be excavated is large, plows are used to advantage. In large excavations where it is necessary to dig to a considerable depth, steam shovels are used. Steam shovels not only loosen the soil but also load it into wagons or buckets.

7. Table I gives an approximate estimate of the number of cubic yards of material of various kinds that can be loosened by the use of picks and plows in a working day of 8 hours. The material is measured in place before loosening.

TABLE I

AMOUNT OF SOILS OF DIFFERENT KINDS THAT CAN BE LOOSENED IN 8 HOURS

	Character of Soil			
	Stiff Clay or Gravel Cu. Yd.	Strong or Heavy Soil Cu. Yd.	Loam Cu. Yd.	Light or Sandy Soils Cu. Yd.
Pick—one man.........	8 to 11	20	16 to 32	32 to 48
Plough {two men two horses}...	60 to 80	160 to 240	320 to 480	640 to 800

8. Removing the Soil.—The implements used in removing the soil from an excavation depend upon the size and shape

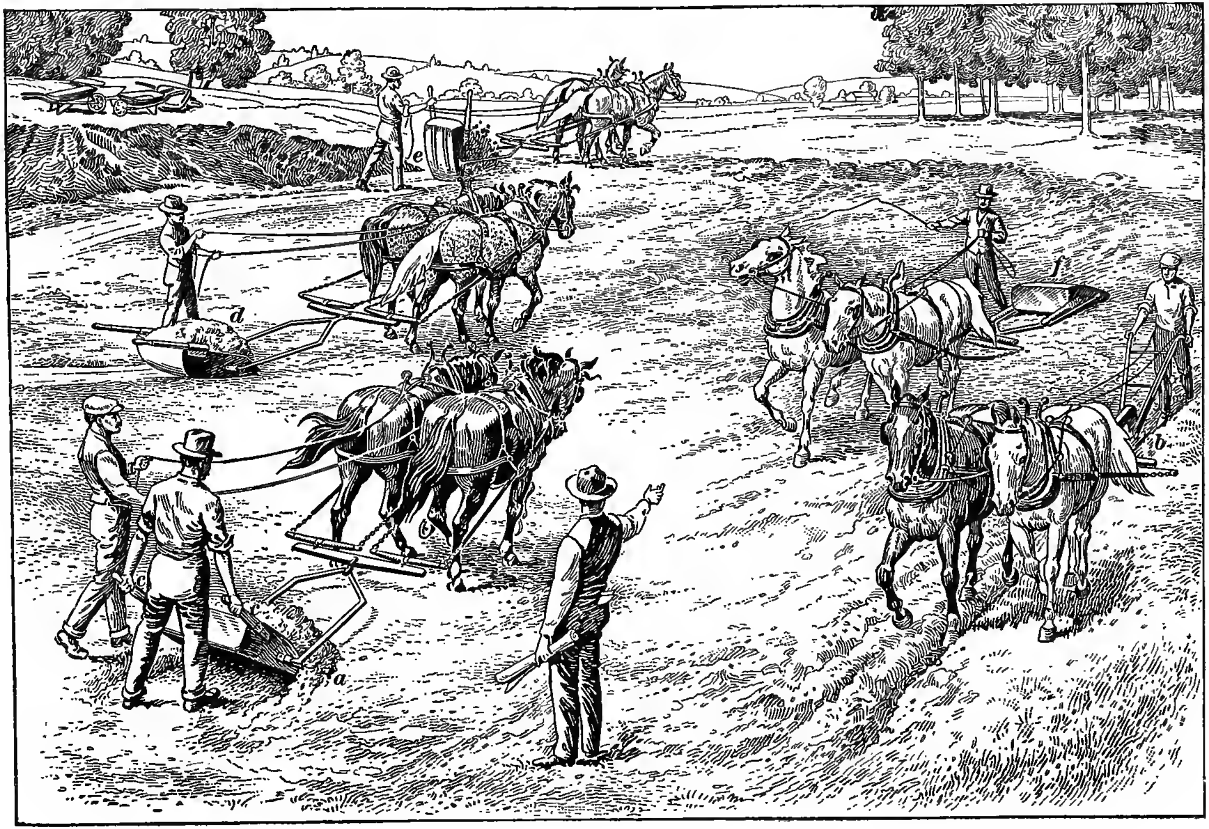


FIG. 1

of the excavation and whether or not the excavated material is to be distributed on land adjacent to the excavation. If the soil is to be distributed over property within a distance of 200 or 250 feet, it will be found economical to use wheelbarrows or drag scrapers; while for a distance of 500 feet, the use of wheel scrapers is more economical. If, however, the excavated material is to be deposited at a greater distance, carts drawn by one horse or wagons drawn by two horses are used.

9. Wheelbarrows.—When the soil is to be deposited at a distance of not more than 250 feet, wheelbarrows are economically used. The wheelbarrows are run along on planks which are laid on the ground and lead to the places where the material is to be dumped.

10. Drag Scrapers.—For conveying material to a distance of 150 to 200 feet, the drag scraper is very efficient and economical. In Fig. 1 are shown drag scrapers which are drawn by teams of horses and managed by either one or two men. Generally, one man is required to manage the team while another man is needed to fill the scraper. As the team moves forward, the edge of the scraper, as at *a*, is pointed down into the dirt, which has been previously loosened by the plow shown at *b*, and scoops up enough to fill it. The handles *c* are then pushed down, which raises the forward edge, and the scraper slides along on the surface of the ground as shown at *d*.

When the dumping place is reached, the handles are raised so that the forward edge catches in the ground and the scraper is turned entirely over, as shown at *e*, and deposits its load. It is then drawn back in an inverted position, as shown at *f*.

When several scrapers are in operation at one time, one man can fill all the scrapers as they return and the driver of each team can easily manage to empty his own scraper as shown at *e*.

11. Wheel Scrapers.—Wheel scrapers are similar to drag scrapers, but are provided with wheels, as shown in Fig. 2. Wheel scrapers are economical to use up to a distance of 500 feet from the excavation. After the wheel scraper scoops up its load, the scraper is raised by means of the lever *a* so that the load is supported on the wheels. The wheel scraper requires two men and two horses for its operation.

12. Carts and Wagons.—Most frequently the soil must be removed to a point at some distance from the excavation, in which case it is best done by the use of carts or wagons. Carts are drawn by one horse and wagons by two horses.

13. Management.—A contractor can save money on his hauling by discovering a place to dump the soil near the excavation. Often he can obtain the privilege of dumping it on some adjacent property where it is desired for filling in, and sometimes he can obtain a small sum in payment for the top soil if it is not needed for grading on the site from which it has been taken.

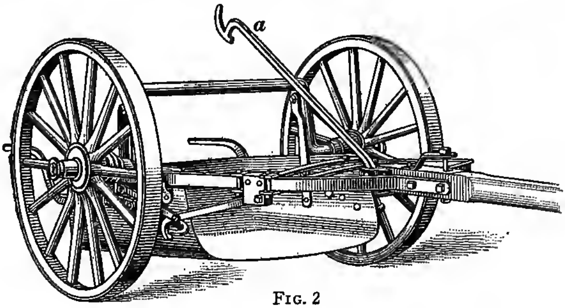


FIG. 2

The contractor, or foreman in charge of the excavating, should use his best judgment in employing the proper proportion of laborers and wagons. The laborers should not be compelled to stop work for lack of wagons to fill, nor should the wagons be standing idle waiting for laborers to fill them. By noting the length of time it takes for a wagon to haul away its load and to return, also the time required for a given number of laborers to fill a wagon, it is possible to estimate the number of wagons that can be filled per day by a given number of men and to adjust matters so that there shall be no loss. In some localities the driver of the cart or wagon will not help in shoveling soil into the wagon. This matter is regulated by the labor unions.

14. Filling Wagons.—In small excavations, the wagons are generally driven or backed into the excavation and the material is shoveled directly into them.

In large and deep excavations, the soil is shoveled into buckets which are raised by means of a derrick and the bucket is emptied directly into the wagon. This method has its disadvantages, for, if the wagons do not come promptly for their loads, the derrick and some of the laborers will be idle

A better method to use in such excavations is to have a large hopper or box built above the sidewalk, as shown in Fig. 3, into which soil is dumped from the bucket as shown at *a*. The material is dropped through the chute *b* into the wagon and when the wagon is filled the chute is closed by a sliding door *c*. By the use of such a hopper neither the bucket nor the wagon will have to wait one for the other.

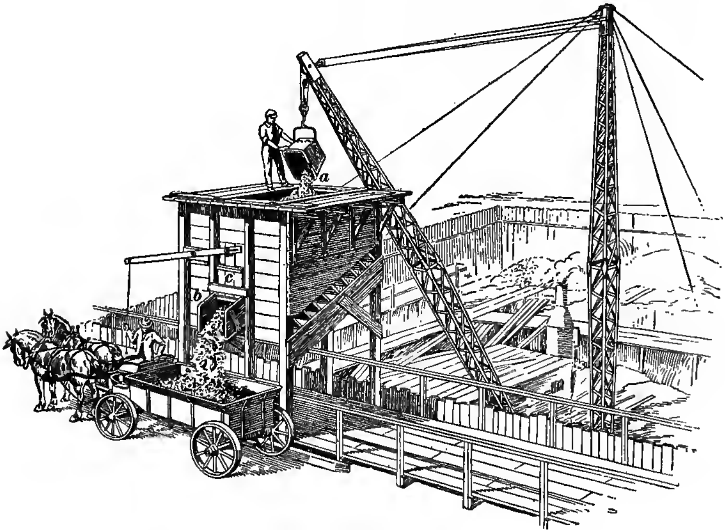


FIG. 3

In some cases the wagon is lifted by the derrick, by means of chains hooked around the axles, and let down into the excavation, and when filled is raised to the pavement, where the horses are hitched to it and it is drawn away.

15. Runways.—When, as is ordinarily the case, the earth is shoveled directly into the wagons, the wagons are driven as close to the shovelers as possible so that they will not have to throw the dirt any farther than is necessary. As the excavation becomes deeper, a temporary runway of earth is left unexcavated, as shown at *a b d c* in Fig. 4. The wagons are driven down the runway and backed in against the embankments *e* and *f*, where they are filled. They are then driven out of the excavation as shown by the curved lines *g* and *h*.

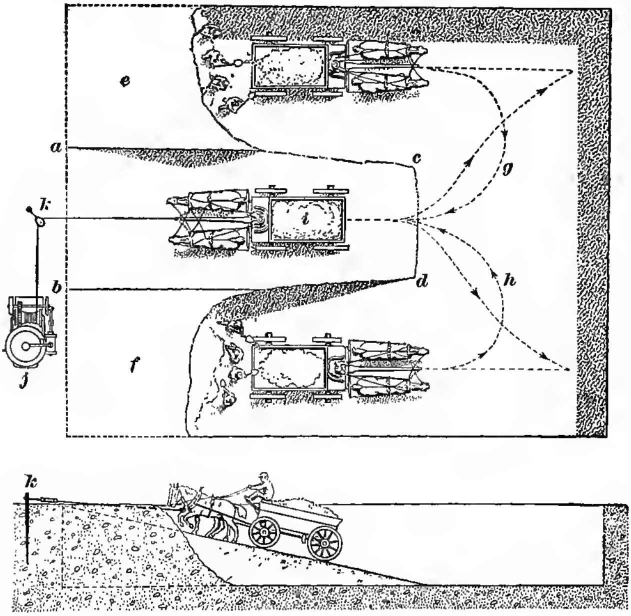


FIG. 4

When all the excavation except this runway has been completed, the wagons are backed down the runway, as at *i*, and the earth forming the runway is shoveled up and into the wagon.

When the runway is very steep, the teams are assisted in hauling the wagon up the runway by another team, or sometimes, as shown in Fig. 4, by a hoisting engine *j* that pulls a rope which passes through the pulley *k* and is attached to the wagon. In cellars covering a large area, the runways are often built of heavy timbers and planks and are also used by the wagons in delivering building materials.

16. Capacities of Wagons, Scrapers, Etc.—Table II gives the carrying capacities and the economical length of haul for wagons, scrapers, carts, and wheelbarrows, also the number of men and horses required to operate them. The capacities given in the table are for loosened earth and not for earth in its original position.

TABLE II

CAPACITIES, ECONOMICAL LENGTHS OF HAUL, ETC., OF WHEELBARROWS, SCRAPERS, CARTS, AND WAGONS

	Capacity Cubic Feet of Loosened Earth	Economical Haul Feet	Operated by
Wheelbarrows	3 to 4	250	1 man
Drag scrapers.........	3 to 7	150	1 man and 2 horses or 2 men and 2 horses
Wheel scrapers........	10 to 17	500	2 men and 2 horses
Dump carts...........	18 to 22	600	1 man and 1 horse
Wagons	27 to 45	1,000	1 man and 2 horses

In cases where the haul is not long, one driver can manage three or four dump carts without difficulty.

17. Swelling and Shrinkage of Soils.—Soils, when loosened up by excavation, increase in bulk about 20 per cent., so that the contractor must calculate upon removing 1.20 cubic yards for every cubic yard of soil measured in its original position. Thus, in figuring on the excavation for a building, if the contractor finds that he will have to excavate 1,000 cubic yards, he will have to figure on carting away 1,200 cubic yards.

If this same soil is placed in a new position and allowed to settle in place, it will shrink until it becomes less in volume than it was originally. Thus, if the 1,200 cubic yards of soil before referred to is placed in a pile it will settle down and shrink until it becomes less than 1,000 cubic yards in volume. This shrinkage varies with different kinds of soils. The shrinkage for sand and gravel is about 8 per cent.; for clay about 10 per cent., for loam about 12 per cent., and for wet soils about 15 per cent.

Example 1.—If the cubical contents of an excavation is 900 cubic yards, how many cubic yards of earth will have to be carted away?

Solution.— $900 \times 1.20 = 1{,}080$ cu. yd. Ans.

Example 2.—How much clay must be excavated from its original position to fill a trench having a capacity of 450 cubic yards, allowing the clay to settle thoroughly?

Solution.—Clay, if excavated from its original position and placed in a new position in which it is allowed to settle, will shrink until it is 10 per cent. less in volume than it was originally. It will therefore have 90 per cent. of its original volume. 450 cu. yd. is then 90 per cent. of the original volume. 1 per cent. is $\frac{450}{90} = 5$ cu. yd. 100 per cent. is $100 \times 5 = 500$ cu. yd. Ans.

In the latter example the original clay will have a volume of 500 cubic yards. When it is excavated and loosened it will have a volume of $1.20 \times 500 = 600$ cu. yd., and when it has settled into a new position will have a volume of $.90 \times 500 = 450$ cu. yd.

TABLE III

WEIGHTS OF EXCAVATED SOILS

Material	Pounds per Cubic Foot	Pounds per Cubic Yard	Cubic Feet per Ton	Cubic Yards per Ton
Sand, loose and dry	90 to 106	2,430 to 2,862	19 to 22	.75 to .81
Sand, moist	110	2,970	18	.67
Sand, full of water	120 to 130	3,240 to 3,510	15.4 to 16.5	.57 to .61
Gravel, dry	90 to 112	2,430 to 3,024	18 to 22	.67 to .81
Gravel, wet	120 to 125	3,240 to 3,375	16 to 16.5	.59 to .61
Clay, dry	110 to 120	2,970 to 3,240	16.5 to 18	.61 to .67
Clay, wet	130 to 150	3,510 to 4,050	13.7 to 15.4	.50 to .57
Loam, dry	80 to 90	2,160 to 2,430	22 to 25	.81 to .92
Loam, wet	105 to 110	2,835 to 2,970	18 to 19	.67 to .72
Rock, solid	165	4,455	12	.44
Rock, broken up.	93	2,511	21.5	.8

18. Weights of Excavated Materials.—In Table III are given the approximate weights of the more common forms of excavated materials in pounds per cubic foot and pounds per cubic yard; also, the number of cubic feet per ton and cubic yards per ton.

EXCAVATION OF ROCK

19. Blasting.—In many cases where rock is encountered it must be broken up by the use of explosives—usually black powder or dynamite—which are exploded in holes drilled in the rock. This work is called **blasting.** In cities blasting is a separate branch of contracting and is usually done under subcontract.

Blasting consists of drilling holes in the rock, placing charges of dynamite or powder in the holes, stopping the holes up, and then exploding the powder, which breaks the rock apart.

When a blast is to be made, a hole to receive the powder is first drilled in the rock by hand or power drills. The holes vary in diameter from ½ inch to 3½ inches and in depth from a few inches to several feet. The direction varies according to the dip, or slope, of the rock and the location of its stratification planes.

20. Where but few or small holes are needed, they are drilled by hand. The drills are steel bars properly pointed. For small and shallow holes, one man in a sitting posture holds a short drill with one hand and strikes it with a hammer held in the other, turning the drill slightly after each blow. For drilling somewhat larger and deeper holes, one man in a sitting position holds the drill and one or two men strike it with sledge hammers. The man holding the drill turns it after each blow to keep the hole cylindrical, occasionally pouring in water and cleaning out the powdered stone with a scraper. When the hole is of sufficient depth, it is dried out with a rag on the end of a wire and is ready for the explosive.

When extensive blasting operations are necessary, especially where large and deep holes are required, rock-drilling machines operated by compressed air or steam are used. These machines drive the drill repeatedly against the rock and rotate the drill slightly at each stroke. For excavation work that is extensive enough to warrant the installation of the plant, the cost of drilling by rock drills is at least one-third less than by hand power.

21. After holes are drilled they are charged with an explosive. If the charge is to be ignited with a match, a fuse is placed in the hole, in contact with the explosive, and dry sand, clay, or some similar substance is tamped or packed down around it. When dynamite is used, the end of the fuse in contact with the explosive is provided with a cap, or detonator, as dynamite can be exploded only by concussion. Frequently the charge is exploded by electricity, in which case the hole is loaded in the manner described, except that wires instead of a fuse connect to the cap, which is fired by a current of electricity from a blasting machine or battery.

22. In order to confine the pieces of rock, which would otherwise be shot into the air after an explosion and cause damage to adjoining property, or possibly loss of life, a number of heavy wooden logs are placed over the rock to be blasted. These logs are bound together by a heavy chain. The weight of the logs keeps the fragments of stone from flying when the charge is exploded. In other cases a heavy matting of thick rope is used, and the matting is held down during the blast by logs of wood or pieces of stone.

23. Wedging.—Where rock must be taken out so close to existing walls that injury might result from blasting, the operation of wedging is resorted to. This operation consists of breaking up the rock with wedges. These wedges are made of steel, about 8 inches long, with wire wound around about them so as to form handles. A workman holds the point of the wedge against the rock, and another man strikes repeated blows on the wedge with a sledge hammer until the rock is split or broken.

When the rock is formed in layers with well-defined seams between them and breaks easily, large quantities may be cheaply removed by this means, but it is a slow and expensive process if the rock is hard and lies in large compact masses.

24. Measurement of Rock.—For the purpose of estimating, rock is measured by the cubic yard as it lies in its original position. A cubic yard of rock, when broken up ready to be carted away from the excavation, will occupy a space of about 1$\frac{4}{5}$ cubic yards.

DEPTHS AND AREAS OF EXCAVATIONS

25. Depths of Cellars.—The depth of the excavation for the cellar depends upon the kind of building that is to be erected. For an ordinary dwelling there should be a depth of about 8 feet from the under side of the floorbeams to the finished cellar floor. In very large houses, especially where they are heated by hot-air furnaces, space should be allowed to accommodate the heating pipes and to permit a man to walk about freely beneath them.

For stores or office and manufacturing buildings, the depth of the cellar must be regulated by the demands of business. In some large office buildings and hotels there are often two or more cellars, reaching in some cases to 60 feet below grade.

In buildings where light must be admitted into the cellars from the outside, the under sides of the floorbeams must be kept at least 2 or 3 feet above the ground level.

26. Excavation for Cement Floors.—If the cellar is to have a cement floor, the excavation should be carried down about 4 or 5 inches below the level of the finished cellar floor to allow for it.

27. Trenches for Footings.—The footings, or spreading courses of masonry at the bases of the walls, should extend below the cellar floor. Trenches are therefore dug to receive the footings of all walls and piers. The bottoms of these trenches must be of solid undisturbed earth or rock, as it is not safe to build upon filled-in material, for, as has been shown, filled-in soil has a tendency to shrink.

If, through some miscalculation or error, the trenches have been carried down farther than necessary, they should be filled in with concrete or masonry and not with soil.

The bottoms of trenches are generally made level, except when water appears in the excavation. In such a case they are given a slight pitch, or fall, so that water will flow to the low point, from which it can be pumped out or drained into the public sewer or an adjacent cesspool.

28. When a mass of rock is encountered in excavations and its surface is sloping, the part under the footings should be leveled off even with the bottoms of the trenches or else cut so as to form level steps, as shown in Fig. 5 at *a*, so that the walls shall rest on level bearings. If there are any pockets or holes in the rock below the bottom line of the footings, as at *b*, these should be filled up solid with concrete.

29. Below Frost.—In all localities where frost and cold occur, the foundations or cellar walls should invariably be carried down to such a distance that frost will not affect them. If the walls are not started below what is called the frost line, the alternate freezing and thawing of the water in the earth tends to throw the walls out of plumb and destroy them.

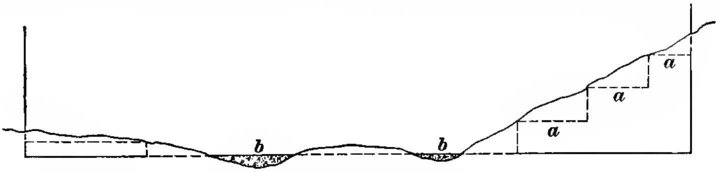


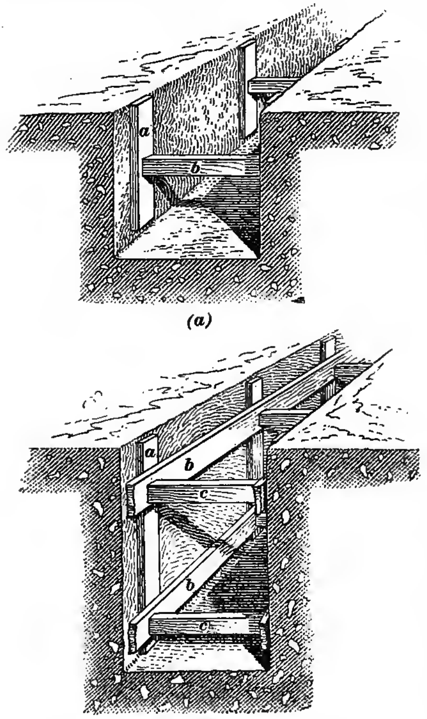
FIG. 5

The depth to which frost will penetrate the earth varies in different parts of the country according to the climate. In most of the New England States, 4 feet is considered the limit. In Canada the frost penetrates as far as 6 feet, while in the southern parts of the United States there is practically no danger from frost.

Frost will penetrate to a greater depth in hard, densely compacted soil than in soft and porous soil, as the porous soil contains numerous air spaces which prevent the transmission of heat and cold.

30. Space for Finishing the Outside of the Wall. In excavating for foundation walls, allowance should be made for reaching the outside of the wall for the purpose of handling stones, brick, etc., and for the forms for concrete, if concrete is used. This space should be from 6 to 12 inches, which will make it possible for the mason to fill the joints on the outside of the wall with mortar.

As a means of protecting the walls from penetration by water, the outsides of the walls are often coated with asphaltum or pitch, and are sometimes plastered with cement. When such operations are specified, the earth must be excavated for a sufficient distance outside the walls to allow of performing them.



(a)

(b)

Fig. 6

MISCELLANEOUS EXCAVATION

31. Supports for Sides of Trenches. There is generally a certain amount of excavating necessary for drain, sewer, gas, and water pipes in connection with the average building. This excavation is generally in the form of trenches and is done with the pick and shovel. There is always danger that the sides of such trenches will cave in or fall into the trench, when the soil is not firm. This is prevented by the use of planks and braces such as are shown in Fig. 6 (*a*) and (*b*). The planks *a* in (*a*) are placed at intervals along the banks and braces *b* are cut in between them. This arrangement is a simple one for a shallow trench. When the trench is deeper, as in (*b*), the boards *a* are held in place by horizontal planks *b*, which are braced by the pieces *c*. These methods are suitable for ordinary cases. In more complicated cases sheet piling is used as is described later on.

FILLING AND GRADING

32. Filling Behind Walls.—The architect generally specifies that the filling around walls and in the trenches shall be done by the mason contractor. The space between the walls and the outside of the excavation should not be filled until the mortar in the walls has had time to set, otherwise the wall may be pushed out of place. This space should be filled gradually with clean earth. The earth may be left to settle in place or it may be packed or tamped into place. A tool for tamping, as shown in Fig. 7, can easily be made by nailing a handle *a* to a short piece of 3″×4″ studding *b*. By tamping the soil in place it will not be necessary to wait for it to settle, for if thoroughly tamped the earth will not shrink. The earth may be packed into place by thoroughly saturating it with water, which is played upon it from a hose while it is being shoveled into place.

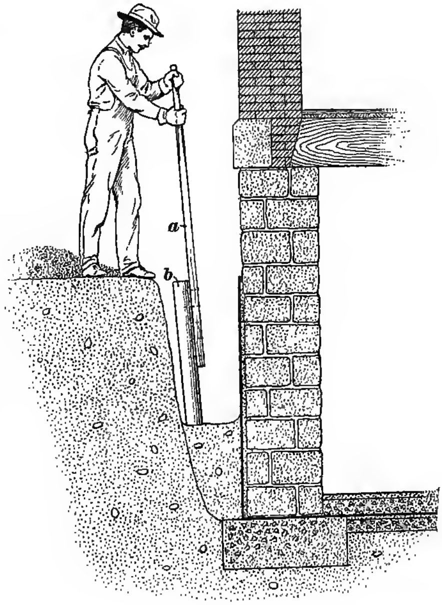


Fig. 7

33. Filling Trenches.—All trenches should be filled with clean earth, and an excess of earth should be piled over the trench to provide for shrinkage. If it is desired to grade over the trench at once, the soil should be tamped as it is placed in the trench or else packed in place with water as just described.

34. Grading.—The architect generally shows the *grade line,* or desired level of the ground where it meets the walls of the building, on the drawings. The ground must be brought up to this line at the house. It may be necessary to fill in or dig away soil to accomplish this. As a rule, the ground is graded so that it pitches downwards, away from the building. This is done so that the rainwater falling close to the building will naturally tend to flow away from the building and will not soak through the ground and the foundation walls.

The loam and sod which have been laid aside for grading should be placed on top of the ordinary soil. This loam placed at the surface will facilitate the growth of flowers and grass.

MEASUREMENT OF EXCAVATION

35. For Level Ground.—The ordinary rules of mensuration are all that are needed to compute the **volume** of any excavation. The work is very simple when the area to be removed is regular; but when the outlines are very irregular and broken, the easiest method to employ in calculating the excavation is to divide the plan into geometrical figures that are easy to compute, and then calculate the area of each one separately. Adding these areas and multiplying their sum by the depth of the excavation will give the volume of the excavation. To this volume must be added the excavation necessary for finishing the outside of the wall as described in Art. **30.**

This method will be made clear by referring to Fig. 8, which represents the plan of an irregular foundation. To compute the area of the excavation, the plan is divided into the rectangles *a d c b, l k b m, j i h g, g f e c,* and the polygons *n q p o, t u r s,* and *a x w v.* By scaling on the drawing the dimensions of these figures, the area of each may then be readily determined by calculation.

36. For Ground With Irregular Surface.—It is sometimes necessary to find the volume of an excavation the surface of which is very irregular, as in Fig. 9. In such a case, the following method may be used: Divide the surface of the excavation as shown on the plan into a number of squares or rectangles. These represent the ends of prisms, such as

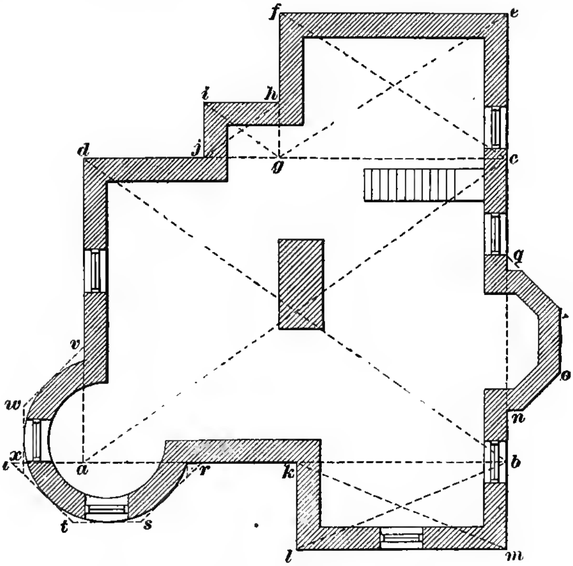


FIG. 8

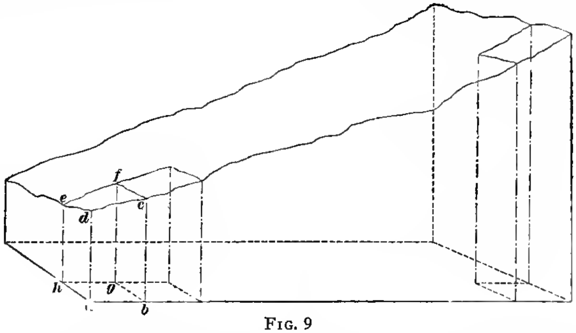


FIG. 9

c d e f a h g b. Then calculate the volume of each prism by ascertaining the height of the four corners above the bottom; add these measurements together, divide the sum by 4 (the number of corners), and multiply the result by the end area, as *a h g b*; the product will be the volume of the prism. The sum of these partial volumes will be an accurate estimate of the contents of the excavation.

WATER IN THE EXCAVATION

37. Rainwater.—In sandy soils there is likely to be very little trouble with water standing in the excavation, as water readily sinks into such soils, below the bottom of the excavation.

Where there is clay, however, water will not percolate through it and will gather in the excavation.

38. Springs.—In cases where the soil is partially rock, springs are often encountered. The water will run into the excavation and must be continually removed by pumps or by draining.

39. Pumping.—When the water tends to stay in the excavation, a low spot should generally be formed into which all the water will flow, and from which it can be pumped out by a hand or a steam pump. This water should be led to some point away from the excavation or into the sewer.

40. Draining to Sewer.—If the water is flowing in from springs, and is likely to flow continuously, some permanent arrangement must be made to remove the water. This can often be done by placing drain pipes under the cellar floor and around the outside of the foundation walls, and leading the water to the sewer or to a cesspool near the house.

41. Waterproofing.—When the soil surrounding the cellar wall of a building contains water that it is impossible to drain away, it will be necessary to waterproof the walls and floor so as to form a water-tight box. The method of doing this will be described later.

SHORING, NEEDLING, UNDERPINNING, AND BRACING

42. General.—When the foundation walls of a building are to be built so as to extend below the foundation walls of an existing adjoining building, shoring, needling, underpinning, and bracing are necessary in order to preserve the stability of the existing building.

This class of work is generally performed by contractors who make a specialty of it, and it is generally left entirely in their charge. They should be held strictly responsible for the proper and safe execution of the work.

The architect should not assume responsibility for the work, but should, however, be familiar with the methods used and should endeavor to see that all due precautions are taken to protect life and property.

SHORING

43. Shoring is a method of temporarily bracing or supporting the walls of a building by means of inclined posts or struts. Shoring is used to brace up an old wall that threatens to fall, or to prevent a wall from falling when an adjoining wall is removed. It is also used to partially support a wall while the lower portions of the wall are being altered or removed.

44. Shores.—Shores are made of sticks of timber of various thicknesses. For shores that are from 15 to 20 feet in length, the cross-section through the timber should be 6 inches by 6 inches. When the shores are from 40 to 50 feet in length the timbers should be 12 inches by 12 inches.

45. Purposes of Shores.—Shores are sometimes used as braces to steady a wall, or hold it in position while excavation is going on next to the wall. This is particularly necessary when the wall is *out of plumb,* or not exactly vertical; or, when it bulges out at the middle as shown in Fig. 10. The shores, in such cases, should be placed with as flat a slope as possible against the wall. Shores such as these are sometimes called *bracing* or *pushing shores.*

Shores are also used to support part of the weight of the wall when alterations are being made at the lower part, or while, as in Fig. 11, the wall *a* is being carried down to a lower bearing, as at *b*. The shores in such cases should be kept as nearly vertical as possible, as at *c*. Such shores are called *lifting shores.*

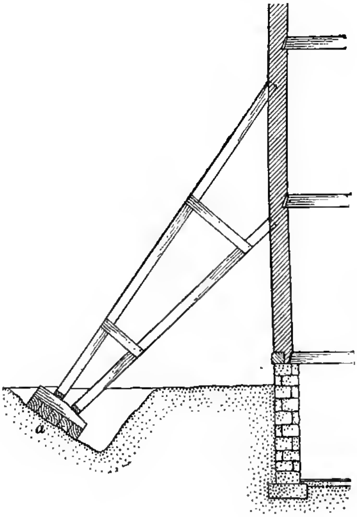


Fig. 10

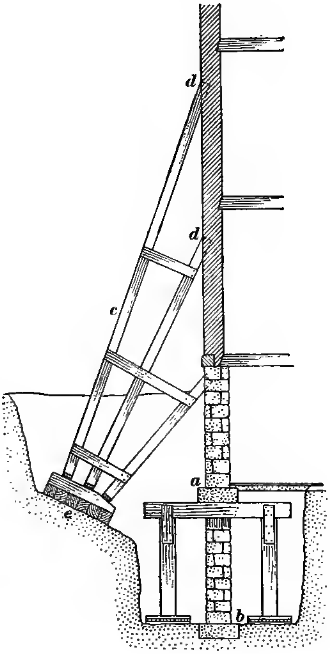


Fig. 11

The upper ends of the shores should be placed in the walls as nearly opposite the floorbeams as possible, so that there will be no danger of the walls being pushed in between the

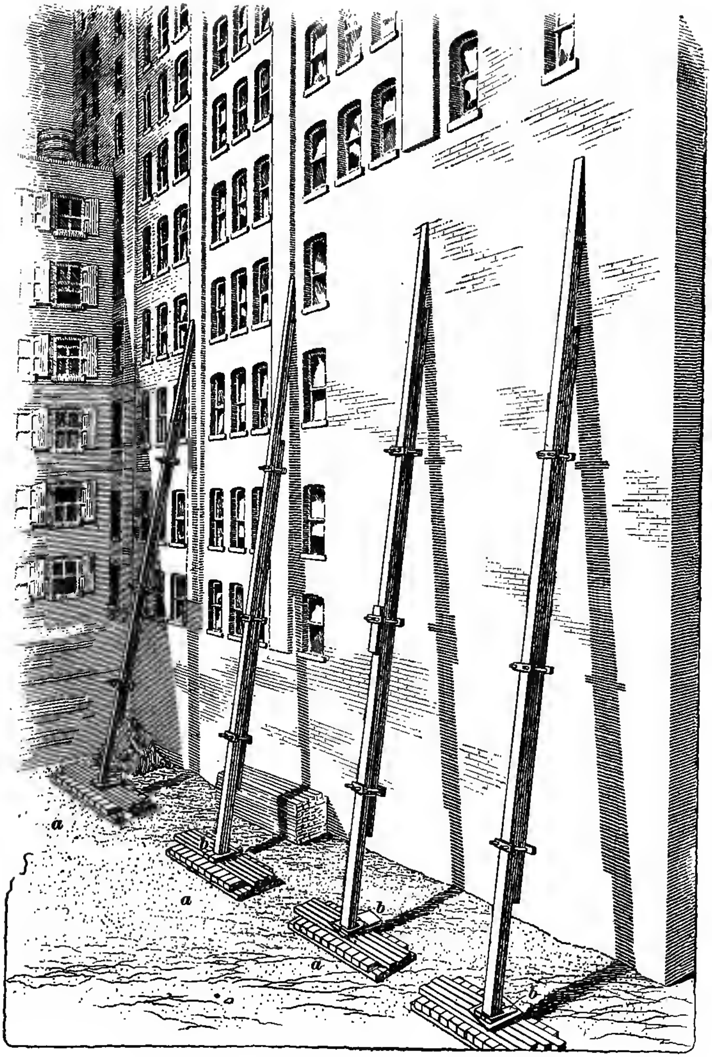


Fig. 12

floor levels. The holes *d* are cut in the wall so that the brickwork will bear firmly upon the shores.

46. Footings of Shores.—The shores sometimes carry very heavy loads and these loads must be spread over the earth in accordance with the resisting power of the soil.

This is done by building footings, or platforms, on which the lower ends rest. If a shore supports 30 tons and rests upon soil capable of sustaining a load of 3 tons per square foot, the shore will require a footing, or platform, having an area of $30 \div 3 = 10$ square feet. The platform should be placed, as nearly as possible, at right angles to the direction of the shores. These platforms, or footings, are shown in Fig. 10 at *a*, in Fig. 11 at *e*, and in Fig. 12 at *a*.

47. Jacks.—Shores that are used in supporting the weight are sometimes driven up by means of wedges such as shown in Fig. 12 at *b*, and sometimes by *screw jacks*, or *jacks*. Wooden wedges should be of very hard wood, and they are capable of lifting the shores with a great deal of power. The effect of hammering such wedges, however, is to jar the wall, and this effect is sometimes injurious.

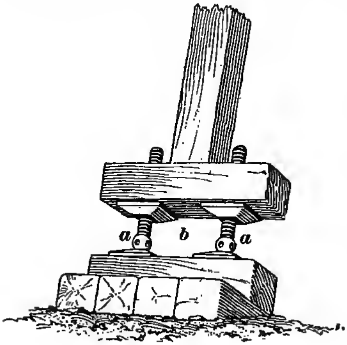


FIG. 13

By the use of jacks, the force used in lifting the shores is applied gradually without jarring the wall. Illustrations of jacks are given in Fig. 13 at *a*. When a single jack is used under a shore, the jack must be left in until the shoring is finished. Where more lifting power is required, two jacks may be used as shown in the figure. When the shore has been forced into place, the space *b* can be filled with timbers and wedges and the load transferred from the jacks, after which the jacks can be removed and used again on another shore.

The screw of a jack is sometimes arranged to work into the end of a shore which is hollowed out for that purpose. This arrangement is shown at *a* in Fig. 14. Such an apparatus is known as a *pump screw.*

48. Hydraulic Jacks.—Hydraulic jacks are sometimes used when great loads are to be lifted, but the loads should not be allowed to rest on them for more than a short time, as they are apt to let off the pressure and allow the shore to drop. Blocks and wedges should be put under the shore as soon as possible after the shore is raised when hydraulic jacks are used.

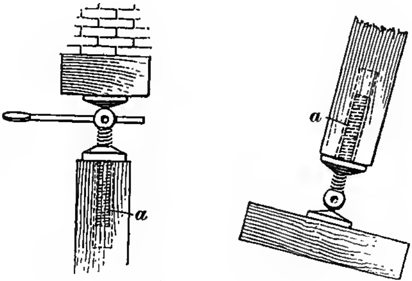


Fig. 14

49. Example of Shoring.—Fig. 12 shows the method that was used for shoring the walls of the Tribune Building, New York, while the foundations of the adjacent building were being laid. Single shores made of 12″×14″ pine, 70 feet long, were used. These shores were each reinforced in the middle by a 10″×12″ stick, 45 feet long. This stick was placed on the under side of the shore and held in place by clamps, as shown. The entire upper end of the shore entered the wall and received a bearing. The wedges rested on timber cribbings 6 ft.×12 ft.

NEEDLING

50. Needling is the process of supporting the upper portion of a wall upon horizontal beams or girders called *needles,* while the lower part of the wall is being altered or provided with new foundations. The ends of the needles are supported by means of vertical posts, jack screws, or timbers piled up horizontally. All of these methods are used to convey the load from the needles to the ground.

The needles may be heavy timbers, as shown in Fig. 15 at *h,* or steel beams, as shown in Fig. 16 at *d.*

Shoring is often used in conjunction with needling, as illustrated in Fig. 11, to support part of the weight of the wall and to prevent any sidewise movement of the wall while it is resting on the needles.

51. The Process of Needling.—In Fig. 15 is shown an illustration of the process of needling. The wall *b* of an existing building is to be carried down to the level *a*, which is the depth of the excavation for the footings of the wall of a new building that is to be erected beside it.

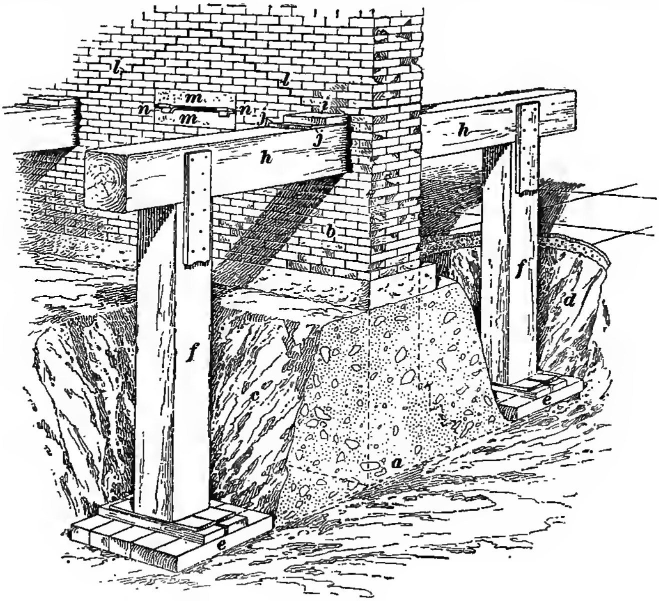


FIG. 15

Pits *c* and *d* are excavated to the level *a*, and are made of sufficient size to receive the timber platforms *e*, which support the posts *f*. These pits should be kept away from the existing wall so as to leave sufficient soil under the old footing to support the wall, as shown in the illustration, until the needles are in place.

The weight to be supported by each needle is roughly estimated by the contractor and he sets the needles at such a distance apart that they shall receive only a safe load. More will be explained about this sort of calculation when the subject of *Design of Beams* is taken up.

The needle *h* is generally a large timber 12 inches by 12 inches, or 12 inches by 14 inches in size, and is pushed through a hole cut in the wall. It is supported on posts *f*. The wall rests directly upon the wooden block *i*, and the wedges *j* are driven between the block and the needle from both sides of the wall, until the weight of the wall above the needle is supported

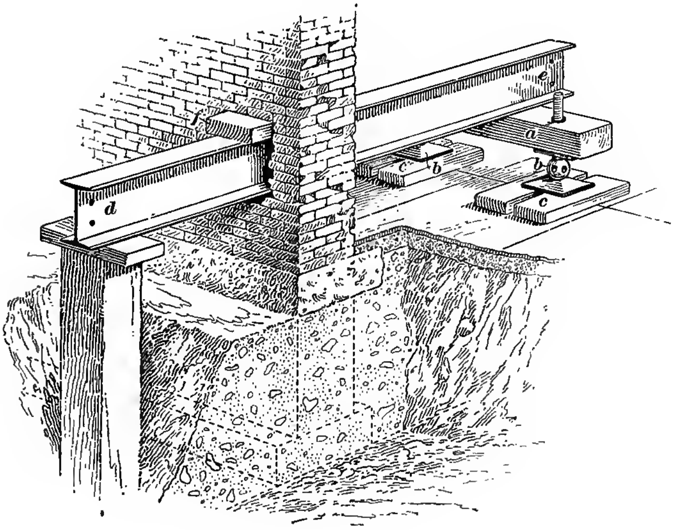


FIG. 16

on the needle. The needle conveys the weight of the wall to the posts *f*, which transmit it to the soil through the footings *e*. These footings must be made of sufficient size to spread the load over the soil so that there will be no settlement.

When all the needles are in place the soil under the wall may be removed. The wall below the needles will probably fall. In any case it should be taken down below the line *l l*, and the new wall should be built up to that line. The extension of the new wall to the level *a* is shown by the dotted lines. This wall should be built as soon as possible so that the strain shall not be sustained by the needles any longer than can be avoided. The footings and wall should, nevertheless, be allowed sufficient time in which to set, before the load of the upper walls is brought upon them, otherwise a settlement might occur which would crack the wall.

52. Steel I-Beam Needles.—Fig. 16 illustrates the use of steel **I** beams as needles, also a method of supporting the end of the needle upon the cellar floor when it projects into the adjacent building. This method does away with the necessity of digging pits in the cellar floor of this building.

The outer end *d* of the needle is supported upon a post in the manner shown in Fig. 15, and the weight of the wall is transmitted to the needle by means of the wooden block *f*, Fig. 16. The end *e* of the needle, which projects into the building, is supported on a cross-beam *a*. This cross-beam rests on jacks *b*, which bear upon the footings *c*, which are made large enough to distribute the load over the floor so as not to crack it.

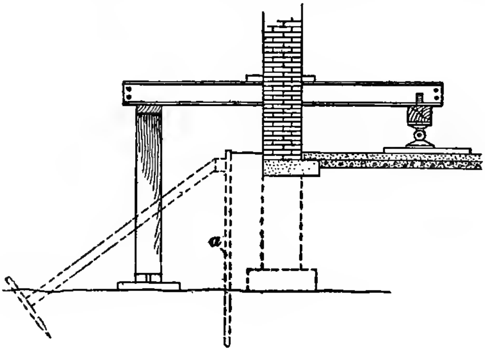


Fig. 17

The weight of the wall is brought to bear upon the needle by raising the cross-beam *a* by means of the jacks *b*. The end of the needle is raised by the jacks until it begins to deflect, or bend, which indicates that the needle is fully loaded.

53. These methods can be successfully used when the soil is firm and will stand up well. The pits should, however, be made only large enough to take the footings under the posts, and should be kept far enough away from the wall so that the earth shall not be squeezed out from under the footings before the needling is in place.

When the soil is compressible or soft and cannot be depended upon to hold up the wall, the earth itself is held in place by means of sheet piling, as shown in Fig. 17 at *a*. Sheet piling will be described later.

UNDERPINNING

54. Underpinning.—The term *underpinning* signifies the process of placing new supports under existing walls, piers, etc., as well as the supports themselves. Thus, the term underpinning, as applied to the wall shown in Fig. 15, refers to the new wall and footing which is built from the level *a* to the line *l l*, as well as the process of building the wall and footings.

This new wall, or underpinning, is carefully built and allowed to set so as to obtain its full strength before the weight of the wall is brought to bear upon it. The process of transferring this weight from the needles to the new underpinning is an important and delicate operation. It is accomplished by the use of stone blocks *m*, Fig. 15, and steel wedges *n*, which are placed between each pair of needles. These blocks should be of a very hard stone. The wall is built up to the level of the lower stone and that stone is set. The steel wedges are then placed upon this stone as shown in detail in Fig. 18. The upper stone is then set upon the wedges. The upper wedges are left projecting so that they may be driven in later. The lower wedge has its end turned down as at *a*, Fig. 18, so that it will not be driven out when the upper wedges are driven in. The masonry is completed and the upper wedges are driven in and will take the weight of the wall above. The

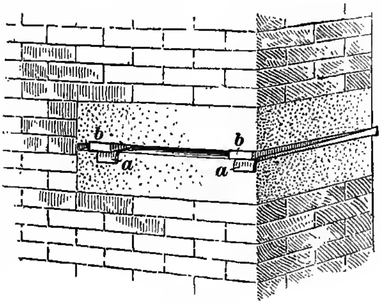


FIG. 18

needles are then withdrawn and the holes where they passed through the wall are bricked up. The joint between the two blocks of stone is then *grouted*, or filled with liquid mortar, leaving the steel wedges permanently in place.

55. Underpinning Without Needling.—Methods of underpinning walls have been devised that do not require needling, thus doing away with the use of bulky needles, shoring timbers, and sheet piling, and the necessity of entering the adjoining property. One method is by the use of brick piers; another is by using steel piles.

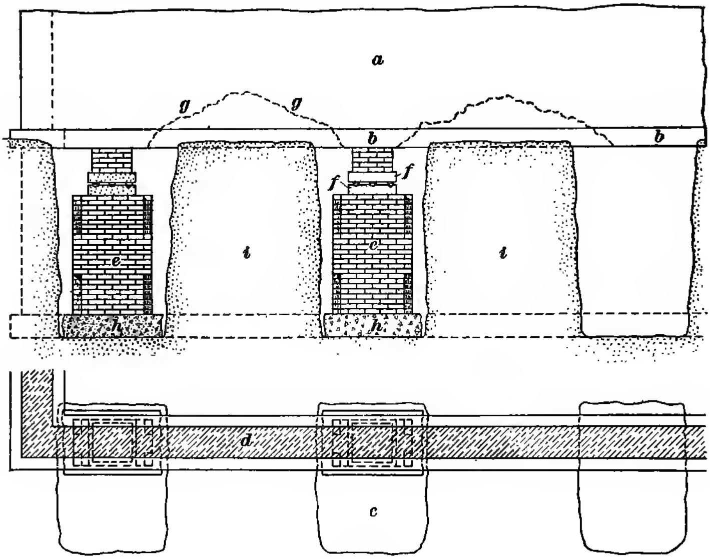


FIG. 19

56. By Means of Brick Piers.—Fig. 19 illustrates a method of underpinning a wall by the use of brick piers. This method can be used where the soil is firm and where the masonry of the old wall is of reasonably good construction. The wall to be supported is shown at *a*, and its footing at *b*. A plan of the wall is shown at *d*. Pits are dug at intervals just outside the old wall, as shown at *c*, and are excavated under the footings of the old wall down to the level at which the new footings are to be started. New footings *h* and brick piers *e* are then built and blocks of stone *f*, with steel wedges between them, are placed as shown in the illustration. When the masonry has set, the wedges are driven up and the load of the old wall is transferred to the brick piers as was described in Art. **54.**

The masses of earth *i* which have meanwhile been supporting the old wall are then dug away and the underpinning is then finished out so as to form a continuous wall. Portions of the old wall may drop, but it is not likely to drop above the line *g g*.

The brick piers may be safely built at intervals of about 10 feet and the wall can be depended upon to support itself between piers that are placed in that way.

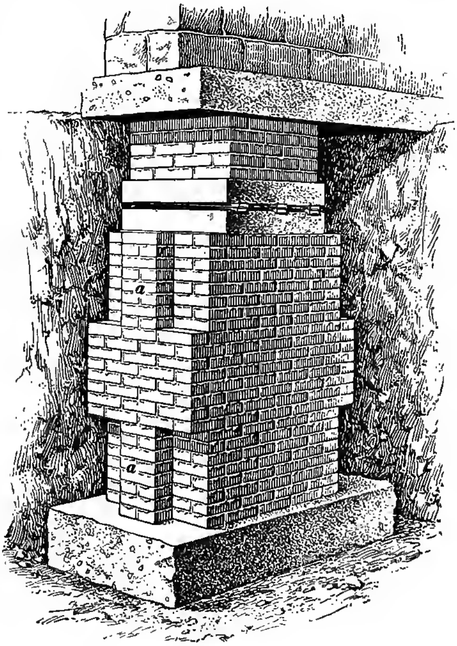


FIG. 20

A perspective view of one of these piers, Fig. 20, shows projections *a*, which lock, or tie, the pier into the rest of the underpinning.

By the use of this method, it is not necessary to enter the old building to obtain supports for needles.

57. By Means of Steel Piles.—A method of underpinning heavy walls, where the soil consists of a layer, or stratum, of compressible soil on top of a stratum of hard pan or rock, is illustrated in Fig. 21. It consists of driving a series of cylindrical steel pipes or piles under the wall at suitable intervals, filling them with concrete, and transferring the weight of the wall to them by means of steel wedges.

The first step in applying this method is to cut **T**-shaped recesses, or *chases,* in the wall at suitable intervals, as shown at *a*. These chases should be large enough to receive the pipe *b* and the jack screw or hydraulic jack *c* which is used in driving the pile into the soft soil. The upper part of the chase is cut so as to receive short lengths of steel beams *d*.

When the chases are cut, the steel beams are put in place. A length of steel pipe is next put in position and a jack *c* is placed between the **I** beams and the length of pipe. The jack presses up against the steel beams and down against the cylinder, or pile, and forces the pile into the ground. After the first length is driven as far as convenient another length is screwed to it and the process is repeated. When the cylinder strikes the hard stratum, the driving is stopped. The interior of the pile is then cleaned out by forcing compressed air into it. Reinforcing rods are then placed in the pile and it is filled with concrete.

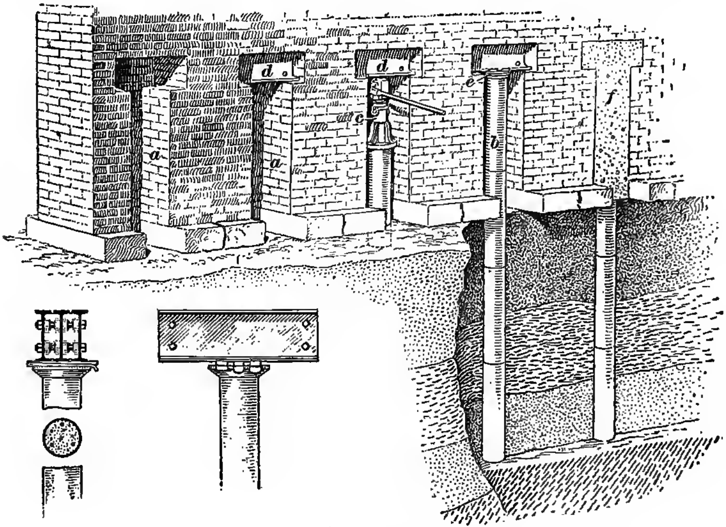


FIG. 21

A metal cap *e* is then placed on the top of the pile and steel wedges are driven between this cap and the under side of the **I** beam, thus bringing the weight of the wall to bear on the pile.

These piles should be driven so that they will be directly under the wall, and care must be taken that they are driven vertically. The last step in the method is to fill the chase in the wall with concrete, enclosing the beams and cylinders as shown at *f*.

Fig. 21 shows the soil partially removed so as to show the piles in their full length resting upon the substratum of rock.

BRACING

58. When adjoining buildings have been built originally with party walls, or walls supporting the floorbeams of two buildings, and one of these buildings is to be torn down, the

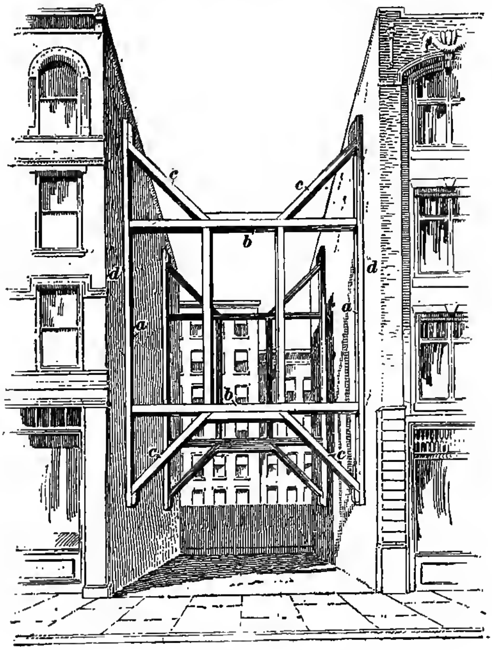


Fig. 22

remaining walls should be guarded against falling by inclined shores. When there are buildings on each side of the lot on which the new building is to be erected, the walls of these structures may be supported by braces.

59. When the distance is not more than 25 feet, the braces may be arranged as shown in Fig. 22. At *a* are 6″×12″ uprights against the walls *d*, to distribute the bearing of the braces; at *b* are the spreaders, and at *c* the angle braces, all of which may be 8″×8″ timbers.

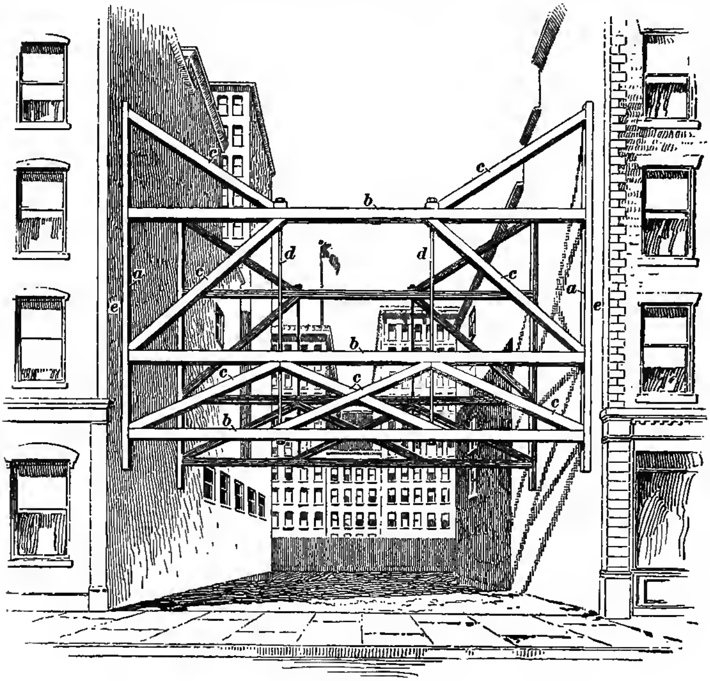


Fig. 23

When the old buildings are from 40 to 50 feet apart, the spreading braces should be trussed, as shown in Fig. 23. The 6″×12″ uprights are shown at *a*, against the walls; the 10″×10″ spreaders at *b*; the 8″×8″ struts and braces at *c*; and the vertical iron or steel ties at *d*. It is preferable to use iron or steel rods for these vertical ties, as they can be readily screwed up, and thus overcome any sagging that may occur in the joints of the truss. One truss should always be placed in the front, another in the rear of the building, and an intermediate one every 25 feet between will generally be found sufficient. Spreading braces are usually built by the carpenter, but it is essential for the architect to know how they should be constructed.

PILING

PILES

60. General.—When it is required to erect a structure upon a site where the soil is soft or compressible and saturated with water, it is generally advisable to support the structure upon piles. If there is a firm stratum of rock, clay, or gravel at a distance of not more than 30 or 40 feet below the surface of the ground, the piles should be driven so that their lower ends shall bear upon that harder stratum.

The piles will then act in the same way as columns. Where there is no firm stratum within 40 feet of the surface, the piles are driven into the soft stratum and sustain their loads by virtue of the friction between the outer surface of the piles and the soil coming in contact with that surface.

61. Bearing Piles.—Piles used to support loads, such as the walls and piers of buildings, are known as *bearing piles*. Bearing piles are formed of trunks of trees, iron pipes, and columns of plain or reinforced concrete. They are driven into the soil until they strike a stratum of hard soil or rock or, where there is no such stratum, until it becomes difficult to drive them farther. When so driven they are capable of supporting heavy loads and form a substantial foundation or support for a building.

62. Sheet Piles.—*Sheet piles,* or *sheet piling,* are used to brace up the sides of an excavation made in soft soil in order to keep them from falling in, or to prevent water from entering the excavation. Sheet piling is formed of boards or planks, sheet steel, or of rolled shapes of steel, such as channels and I beams.

BEARING PILES

63. Bearing piles, as has been stated, are made of wood, steel, concrete, and reinforced concrete.

64. Wooden Piles.—Wooden piles consist of the trunks of trees. They should be straight and sound and have all projections cut off. They are sometimes driven with the bark on and sometimes with the bark removed.

65. Kinds of Woods Used for Piles.—The following-named woods are used for piles: oak, longleaf pine, Douglas fir, tamarack, eastern white and red cedar, chestnut, western cedar, redwood, and cypress. Beech, ash, basswood, and palmetto are also used. The most serviceable of these are white oak, Douglas fir, and longleaf pine. Cedar piles are good for long service. Longleaf pine or Douglas fir are used where very long piles are required. When piles are to be used in positions where the upper parts are alternately wet and dry, longleaf pine, post oak, and palmetto are especially valuable.

66. Sizes of Wooden Piles.—Wooden piles should not be less than 6 inches in diameter at the small end, or *point*. Piles 25 feet or less in length should be not less than 10 inches in diameter at the thick end, or *butt*. When the piles are more than 25 feet in length, the butt should be not less than 12 inches in diameter.

67. Protection of Piles.—Wooden piles that are alternately wet and dry will sooner or later decay. Piles that are driven below the water level, or in soil that is always saturated with water, so that they are always wet, will last for centuries. When piles are driven in wet soils the heads should be cut off below the water level so that the entire pile shall always be wet.

When wooden piles are driven where they are in contact with sea-water, they are liable to be attacked and destroyed by wood-boring worms. The bark is left on the pile in such cases, as it seems to afford some protection to the wood.

Piles are often treated by saturating them with creosote. This treatment prevents the attacks of the wood borers and also prevents rotting of the wood caused by its being alternately wet and dry.

68. Spacing of Piles.—Piles should be spaced not more than 3 feet apart unless the load to be supported is very light, in which case they may be placed farther apart. They should not be spaced less than 2 feet apart.

69. Driving Wooden Piles.—Piles are driven by means of machines called *pile drivers* and *steam pile hammers,* which will be described later. The piles are generally driven with the points down. The butt is cut off square to receive the blow of the hammer squarely. The small end, or point, is sharpened and is often shod with iron, so that it may penetrate the soil more easily. Three types of iron shoes for wooden piles are shown in Fig. 24 (*b*), (*c*), and (*d*).

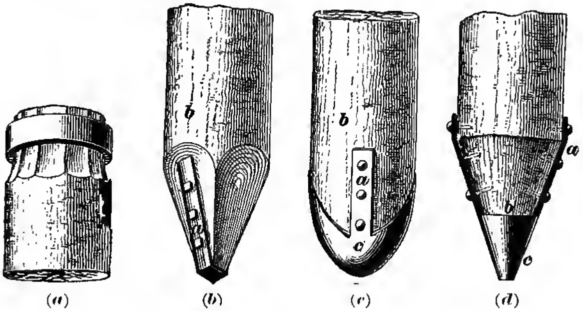


FIG. 24

The butt of the pile is apt to be shattered or splintered by the repeated blows of the hammer. To prevent this splintering, which is called *brooming,* the butt of the pile is generally protected by an iron ring placed over it as shown in Fig. 24 (*a*).

70. Capping of Piles.—Where required, there is placed on the tops of the piles a construction called a *capping* that tends to tie the heads of the piles together, to provide a platform upon which to rest the footings of walls or piers, and to distribute the load equally on all the piles.

There are three methods of capping piles in common use. These methods are shown in Fig. 25. In (*a*) is shown an example of a **grillage capping,** which should be constructed of hardwood, laid below the water level and composed of timbers not less than 6 inches in thickness all thoroughly bolted together.

In (*b*) is shown an example of **granite, or stone, capping.** This consists of blocks of stone laid on the tops of the piles. The tops of the piles should be cut off to a true surface so as to provide an even bearing for the stones.

A **concrete capping** is shown in (*c*). This consists of a solid bed of concrete formed around the heads of the piles for a depth of at least 12 inches. This makes a very satisfactory capping.

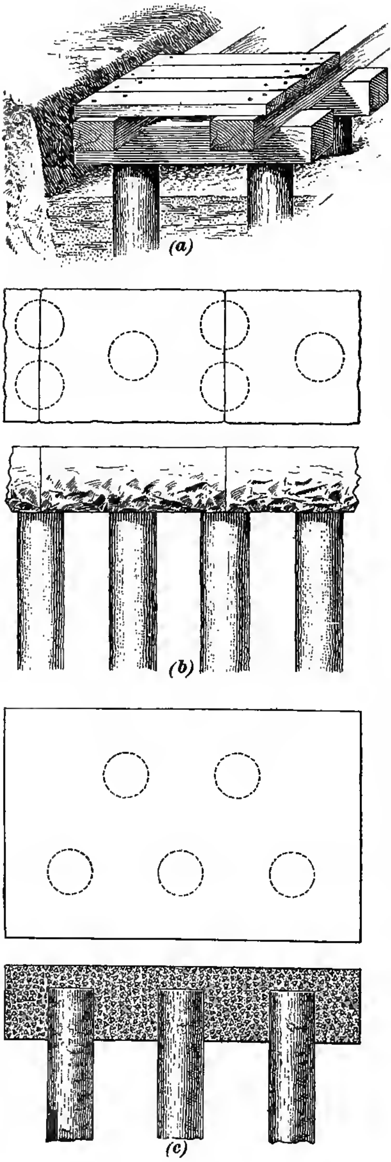


FIG. 25

71. Sand Piles.—A sand pile, Fig. 26, is made as follows: An ordinary wooden pile is driven into the ground for a distance of 5 or 6 feet and then withdrawn. This operation leaves a hole with the soil tightly packed around it. The hole is filled with sand, which is packed into it. This process not only compacts the soil but the sand thus confined will support as much as a wooden pile. The bearing power of a sand pile depends on the friction against the soil on the sides of the pile and on the bearing value of the soil at the bottom of the pile.

72. Metal Piles.—Steel pipes or tubes are used as piles. They are of the same diameter as the wooden piles, and can be made of any required length by screwing short sections together. These metal piles are driven until they strike rock; then they are cleaned out by means of compressed air, reinforcing rods are inserted, and concrete is poured in. These piles are used in underpinning, and are shown in Fig. 21.

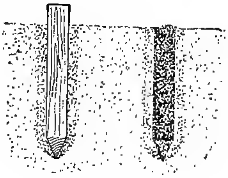


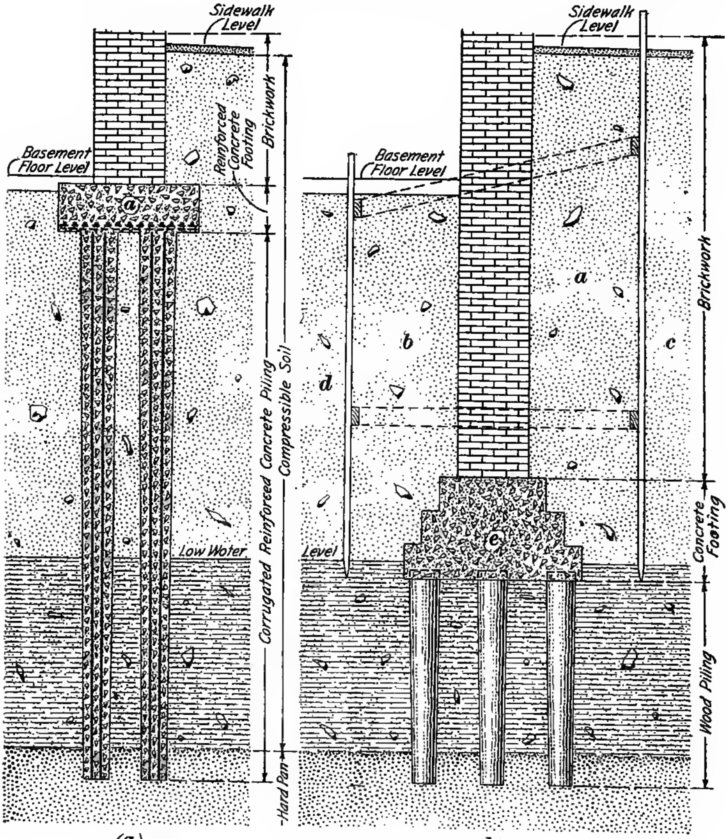
FIG. 26

73. Concrete Piles; Methods of Construction.—Concrete piles are made by driving steel molds into the ground and pouring concrete into them. In some cases the molds are left in the ground and in others the mold is withdrawn. Concrete piles are also made in wooden or metal molds above ground and are either driven into the ground or placed in holes specially prepared to receive them.

74. Advantages of Concrete Piles.—Concrete piles are much more durable than wooden piles, especially when exposed above the water level. They are not subject to decay or to the attacks of boring insects, and will support at least twice the load that a wooden pile of the same size will support. The cost of concrete piles is greater than that of wooden piles, but fewer of them will be required to do the same work. It is not necessary to cut off concrete piles below the water level and therefore it is not necessary to start the capping and footings at the water level, as must be done when wooden piles are used.

An example of the application of wooden piling and concrete piling, illustrating the economy in using concrete piles, is given in Fig. 27.

The walls shown in Fig. 27 at (*a*) and (*b*) support the same load. In (*a*) the wall is shown supported on concrete piles.



(*a*) Fig. 27 (*b*)

The piles extend down to hard pan and project above the water level. The footing *a* is placed just below the basement floor where it will require the least amount of excavation.

The wall in (*b*) is supported on wooden piles which must be cut off below the low-water line. The capping *e* of the piles must therefore begin below the water-line as shown. This involves the excavation of the masses of earth *a* and *b* and the necessity of bracing up the banks *c* and *d* with sheet piling. Braces, which hold the sheet piling in position, are shown by dotted lines. The masonry will have to be carried down as shown. During the building of the capping *e* and possibly during the building of the lower part of the wall, it may be necessary to pump water out of the excavation.

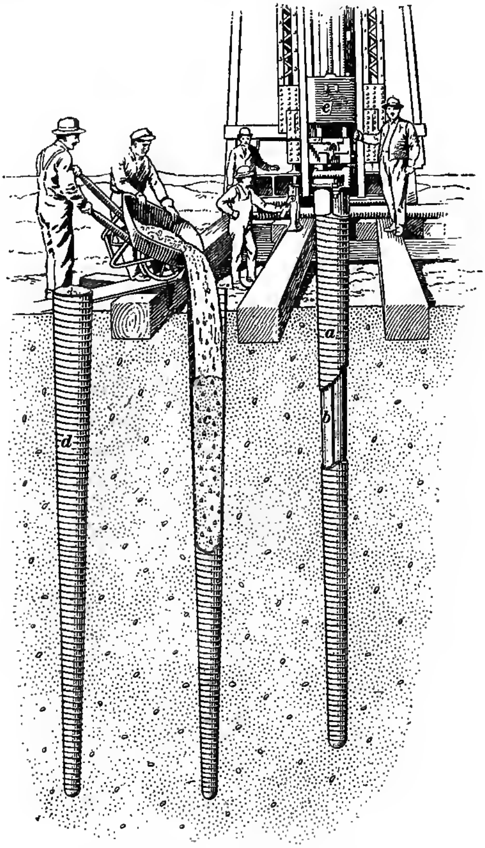
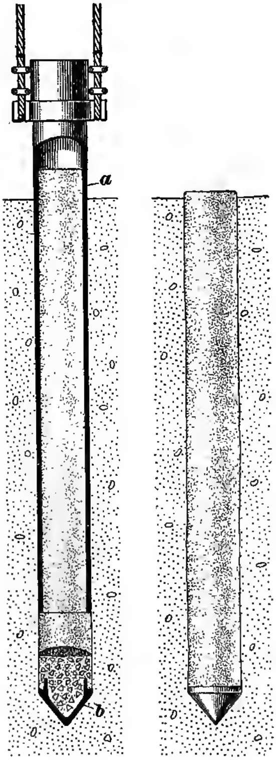


Fig. 28

After the foundation has been built, the soil must be filled in at *a* and *b* and the sheet piling either cut off or withdrawn.

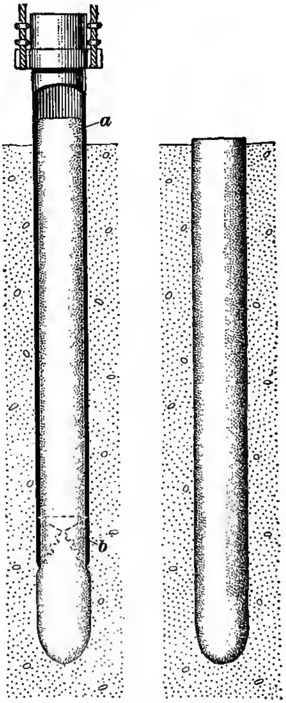
It will therefore be seen that under similar conditions a decided saving can be made by using concrete piles instead of wooden piles.

75. Piles Molded in the Ground.—The **Raymond pile,** shown in Fig. 28, is an example of a pile molded in the ground. A spirally reinforced metal shell *a,* containing an expanded core *b,* is driven into the soil until it cannot be driven any farther. The core *b* is then collapsed and withdrawn, leaving the metal shell in the ground. This shell is then filled with concrete as shown at *c.* The finished pile is shown at *d.* The hammer of the pile driver is shown at *e.* A much stronger



(a) (b)

FIG. 29



(a) (b)

FIG. 30

and stiffer pile is made by placing steel reinforcing rods in the shell before the concrete is poured in.

76. The Standard Simplex Concrete Pile.—The Standard Simplex concrete pile is formed in the soil by either of the two methods illustrated in Figs. 29 and 30. The first method, shown in Fig. 29, consists of driving into the soil a heavy steel cylinder, or form, *a*, which is provided with a cast-iron point, or shoe, *b*. The form is filled with concrete and then withdrawn, and the concrete settles into the hole and entirely fills it. The cylinder is shown, partially withdrawn, in (*a*). The finished pile with the cast-iron shoe in place is shown in (*b*).

77. The second method is illustrated in Fig. 30. In (*a*) is shown a hollow steel cylinder *a* furnished with hinged jaws *b*. A detail of these jaws is shown in Fig. 31. The jaws are closed, while the pile is being driven, and form a point. When the cylinder is pulled up the jaws open to the full diameter of the pipe, as shown at *b*, Fig. 30. After the cylinder has been driven to the required depth, it is filled with concrete and is gradually withdrawn, allowing the concrete to fill the hole in the soil. The finished pile is shown in (*b*). In this method the point is not lost as happens in the previous method.

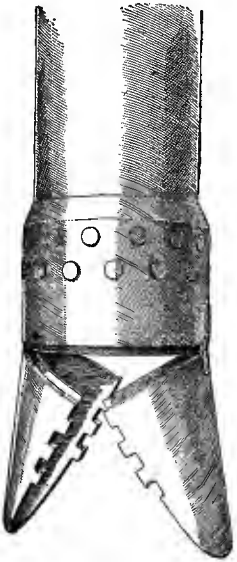


FIG. 31

78. The Pedestal Pile.—Another form of pile that is cast, or formed, in place is the pedestal pile. The various processes used in forming these piles are shown in Fig. 32. The core *a*, view (*a*), and the cylindrical casing *b*, are first driven to the required depth. The core is then removed and a charge of concrete is dumped into the bottom of the hole as at *c*, view (*b*). The core is then used as a rammer to force this concrete into the surrounding soil as shown in (*c*). The pouring and ramming of the concrete are continued until the ball of

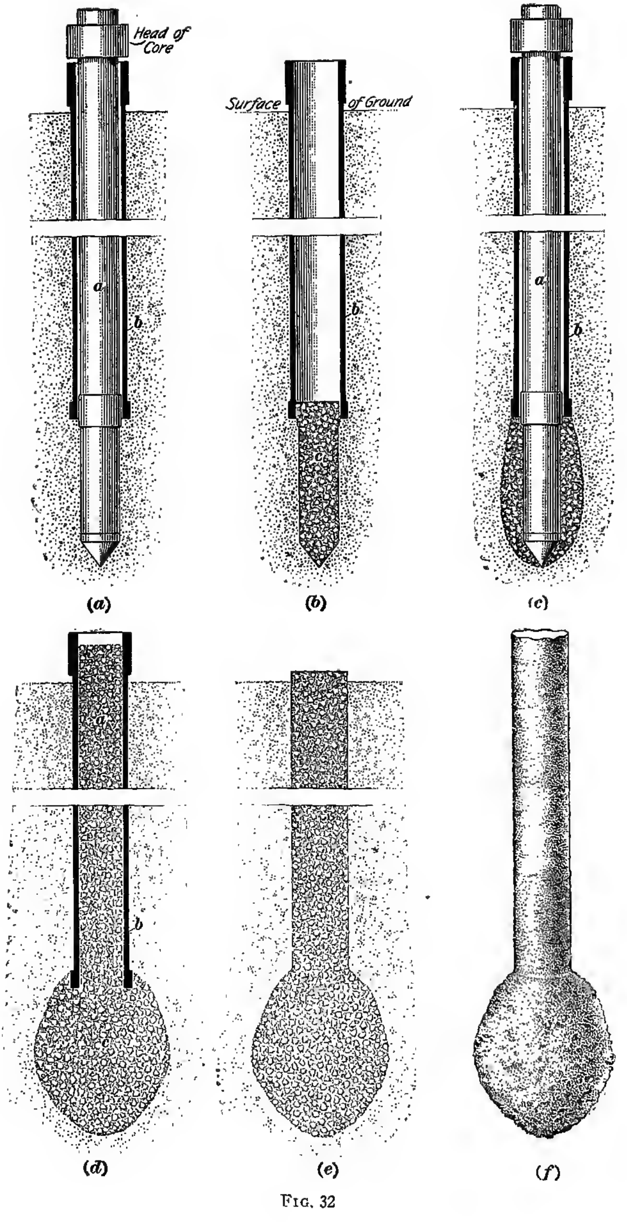


Fig. 32

concrete at the base is about 3 feet in diameter, as shown in (*d*). The base being completed, the cylindrical casing is filled with concrete, as shown at *a*, view (*d*). The casing is then withdrawn and the concrete entirely fills the hole, leaving the finished pile as shown in (*e*). View (*f*) represents a pedestal pile removed from the ground, and shows the large bearing surface at the bottom of the pile.

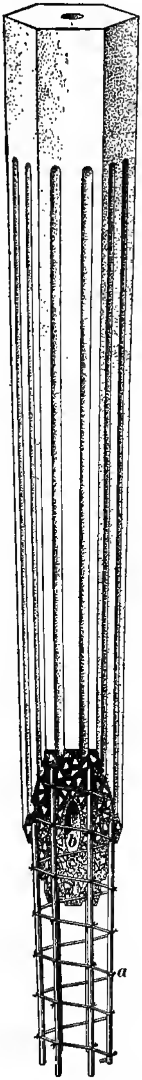
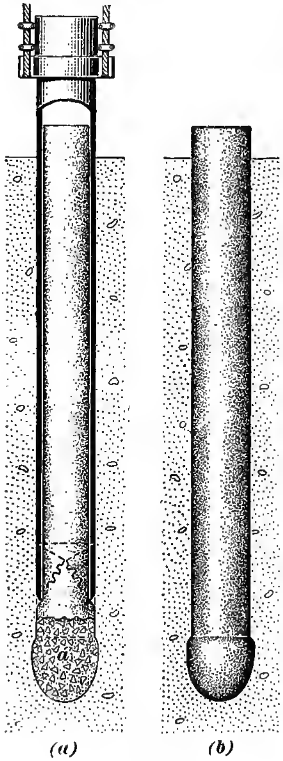


FIG. 34

79. Piles Molded Before Driving. The Simplex molded pile is illustrated in Fig. 33. In forming this type of pile, the shell, which can be seen in view (*a*) and which has the hinged-jaw device already described, is driven until a solid bearing is reached. Several buckets of concrete are then dumped into the shell and the shell is partly withdrawn, and the concrete well rammed. When this is accomplished, several buckets of grout, which is a thin mixture of cement and water, are poured into the form. A concrete pile, which has been molded and seasoned above ground, is then lowered into the shell. The shell is now gradually withdrawn and the grout fills out the space which was



(*a*) (*b*)

FIG. 33

occupied by the shell. The grout adheres to the pile and fills the space between the molded pile and the surrounding soil. The finished pile in place is shown in view (*b*).

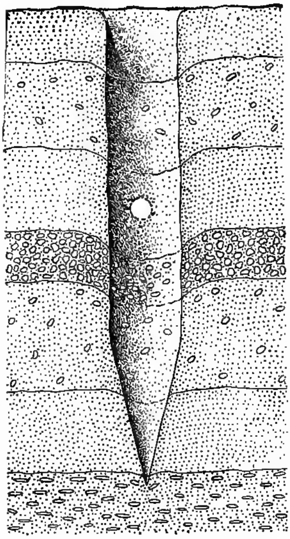


FIG. 35

80. Fig. 34 shows a molded concrete pile of hexagonal section with grooves on each face. The figure also shows clearly the reinforcement of the pile at *a*. The hole down which a water pipe passes is also shown at *b*.

In sinking this pile, a water jet is used in conjunction with the hammer. The *water jet* consists of a 1½-inch pipe connected up to a high-pressure pump and passing down through the hole in the pile. The water which is forced through this pipe loosens up the earth at the bottom of the pile and forces it up through the grooves on the outside of the pile.

81. The Compressol System.—This system is not a true piling system but is very similar and is therefore considered here. A hole, as shown in Fig. 35, is formed by repeatedly dropping a heavy weight having a sharp point, as shown in Fig. 36 at *a*. This hole is then filled with concrete and the concrete rammed into place by a weight of the shape shown in Fig. 37. This weight forces the concrete out so as to form the spread base shown in Fig. 38.

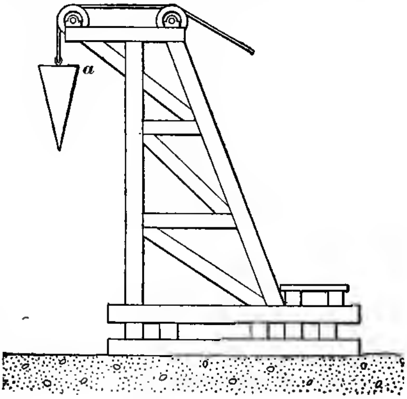


FIG. 36

SHEET PILING

82. Sheet piling consists of a wall of steel or wood driven vertically into the ground at the sides of an excavation. This wall protects the adjoining property, sidewalks, etc. from injury by the caving in of the bank during excavation. Sheet piling is also used to keep back mud, sand, water, etc. when excavating in a wet place.

FIG. 37

83. Wooden Sheet Piling.—An example of wooden sheet piling is shown in Fig. 39, which shows an excavation being made for a sewer. The sheet piling consists of rows of planks *a*, having sharpened lower ends, driven vertically along each bank, and braced by means of braces *d*, extending across the trench. Generally the soil will stand while the trench is excavated to a depth of about 4 feet, and for this depth the planks can be placed horizontally, as shown, and supported by extra-long plank piles *a* driven inside at regular intervals. Braces *d* are put in place to support the tops, and horizontal timbers *c* with braces *d* are placed as shown. Plank piles *a* are then driven down between the planks *b* and the timber *c* till the intervals between the piles first driven are filled. Excavation is then continued down to within a foot or two of the bottom of the piles.

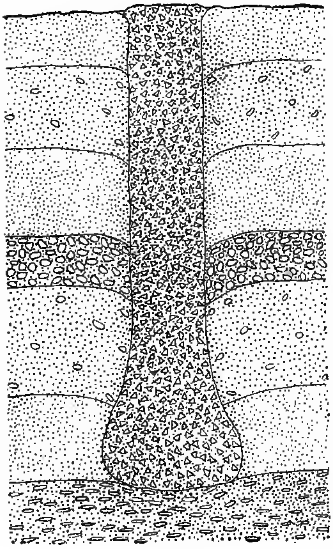


FIG. 38

If the trench is to be still deeper, as in Fig. 39, a horizontal supporting timber, called a *wale*, is put in at the bottom, and inside this at intervals other piles *a* are driven down and held firmly against the wale by timbers *c* and the braces *d*. Then the row of piles is completed by driving them between the wales and the timbers *c*. The excavation can then be continued to the bottom of the second row of piles if other timbers *c* and braces *d* are put in place as shown.

The horizontal planks *b* may be in ordinary stock lengths, such as 12, 14, or 16 feet. The planks should be 2 inches in thickness. A length of about 7 feet is generally preferred for the vertical planks, or piles, which may be as thin as 2 inches if sufficiently supported. One row of such piling, in connection with the horizontal planking, will be sufficient for a depth of

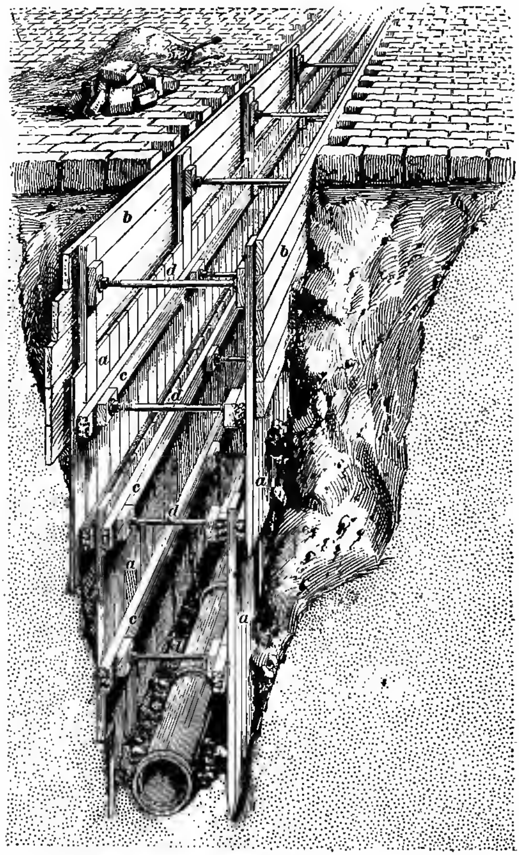


FIG. 39

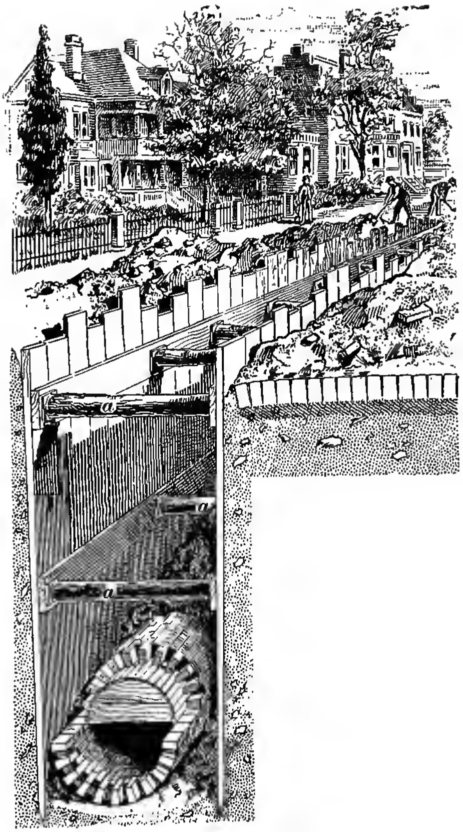


FIG. 40

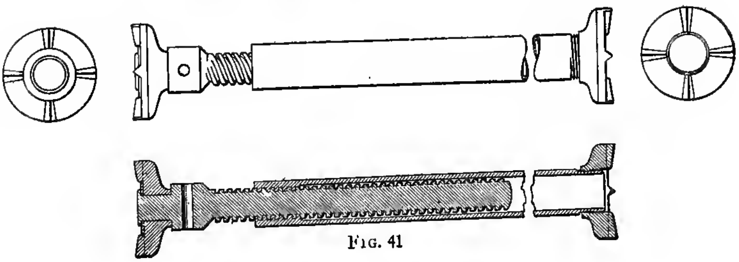


FIG. 41

8 or 9 feet. For greater depths, two or more rows of piling must be driven as shown in the figure. The horizontal timbers *c* are generally 3 in.×6 in. in cross-section.

Another form of wooden sheet piling suitable for use where the depth of the trench is not too great is shown in Fig. 40.

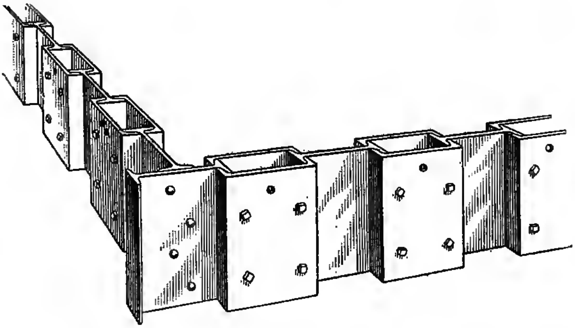


Fig. 42

84. Cross Braces.—The cross braces are sometimes formed of short lengths of rough timber, as shown in Fig. 40 at *a*, or by adjustable iron screw braces, as shown in Fig. 39 at *d*, and as shown in detail in Fig. 41. These braces can be used any number of times, can be adjusted to fit any width of trench within reasonable limits, and can be quickly put in place and removed, or tightened, without jarring.

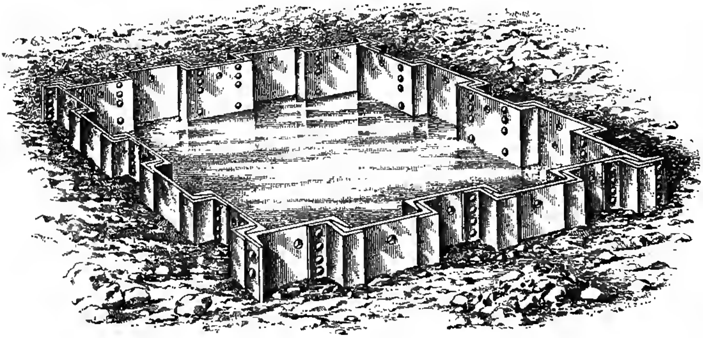


Fig. 43

85. Steel Sheet Piling.—Steel sheet piling, of which there are several designs on the market, has several advantages over wooden sheet piling. It is easier to drive; it is stronger; it will last longer; it can be used more than once; when it is worn out, it can be sold as scrap iron and made into new piling, whereas worn-out wooden piling cannot be used for anything except firewood.

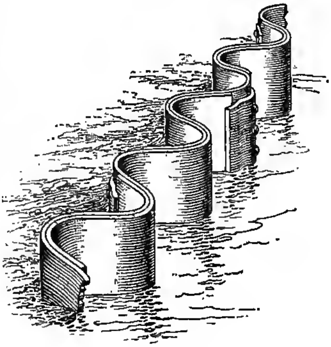


FIG. 44

86. There are several patented forms of steel sheet piling in use. The **Jackson piling** is shown in Fig. 42. This piling is made up of structural steel **I** beams and channels. The channels are bolted together in pairs and are driven together.

Fig. 43 illustrates the **Friestedt interlocking channel-bar piling.** **Z** bars are riveted to channels to act as guides for the adjacent channels.

The **Wemlinger piling** is shown in Fig. 44. It consists of heavy corrugated steel plates. On each plate is riveted a small plate which acts as a guide for the adjacent plates.

A very satisfactory and much used form of sheet piling is shown in Fig. 45 and is known as the **United States steel sheet piling.** These piles consist of one pattern that permits of one pile being fitted into the adjacent pile.

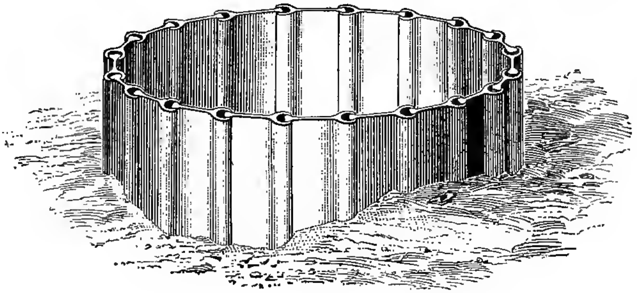


FIG. 45

DRIVING PILES

87. Methods of Driving Piles.—Piles are generally sunk by a machine known as a pile driver. There are two kinds of pile drivers in common use; namely, the *drop-hammer pile driver* and the *steam-hammer pile driver.*

Fig. 46 illustrates a type of **drop-hammer driver.** The hammer is shown at *a*. This weighs from 1,000 to 3,000 pounds and is raised and dropped on the pile repeatedly and acts like a huge hammer. The blows of this hammer upon the head of the pile have a tendency to splinter the pile, and an iron ring is fitted over the head of the pile, as already described, to prevent splitting or brooming.

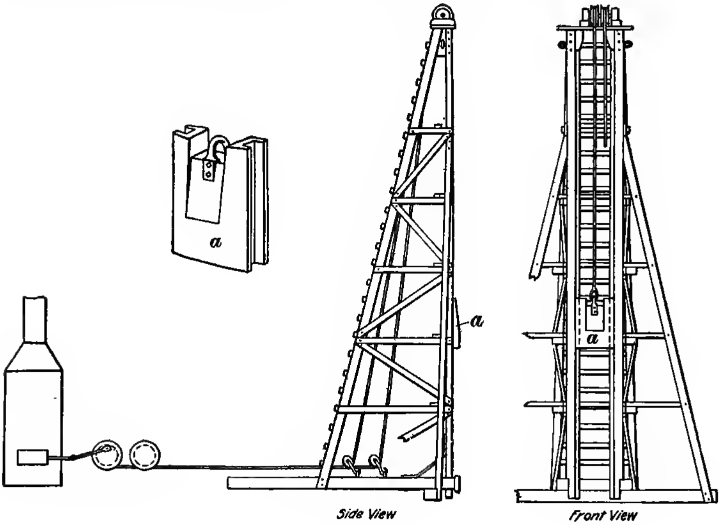


Fig. 46

A **steam-hammer pile driver** differs from a drop-hammer machine in that the hammer is operated by steam. When the pile is in place, the whole apparatus, shown in Fig. 47, is lowered on top of the pile by means of a derrick. Steam is turned on and the hammer begins to work, striking rapid blows and following the pile as it descends.

In Fig. 47 the steam hammer is seen resting directly on a steel pile. A workman is testing the pile with a level to find out if it is plumb. If it is not, he can adjust it by hammering the wedges shown at the bottom of the figure.

88. Driving Sheet Piling.—Wooden sheet piling, such as illustrated in Figs. 39 and 40, is usually driven by means of a large heavy wooden hammer, or maul, which is used by a laborer. On extensive work, especially where patent sheet piling is used, a steel hammer is employed.

89. Bearing Capacity of Piles.—As has been stated, there are two types of piles. A pile of type 1 acts as a column, having a bearing on solid rock or hard soil; one of type 2 sustains its load entirely by virtue of the friction between the surface of the pile and the surface of the soil coming in contact with the pile. A type 1 pile acts as a column especially if the soil through which it has been driven is very soft. If, however, the soil is quite firm so that the pile is prevented from bending under its load, the pile will fail by direct crushing and its strength will be equal to the force required to crush the material of which the pile is made.

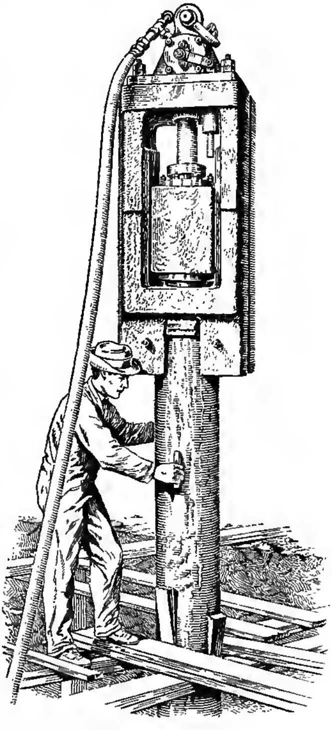


FIG. 47

EXAMPLE.—If a pile has a diameter at the butt of 10 inches and is of yellow pine, (*a*) what load will be required to crush the pile? (*b*) What is the safe load for such a pile?

SOLUTION.—(*a*) Yellow pine will require a force or load of 7,000 lb. per square inch to crush it. The area of the top of the pile is $10^2 \times .7854 = 78.54$ sq. in. $78.54 \times 7{,}000 = 549{,}780$ lb. = about 275 T. Ans.

(*b*) It is customary to use only $\frac{1}{10}$ of the crushing value of wood in actual practice; in other words, a *factor of safety* of 10 is used. Hence, the safe load for such a pile is 275÷10, or 27.5 T. Ans.

90. Engineering News Formula.—The bearing capacity of piles of type 2 which are supported by friction against the soil, when driven by a drop hammer, is calculated by the formula known as the Engineering News Formula, which is used in the best practice and recommended by the building laws of several cities. It is as follows:

$$W = \frac{2PH}{a+1}$$

in which W = safe load, in tons, or bearing value of pile;

P = weight of hammer, in tons;

H = fall of hammer, in feet;

a = penetration of pile, in inches, produced by last blow of hammer.

When the formula is to be used for a steam pile driver the denominator is changed from $a+1$ to $a+.1$.

The penetration of a pile under the last blow is considerably affected if the head of the pile is broomed, and in order to obtain correct results when driving test piles the broomed heads should be cut off before the last blow is struck.

EXAMPLE.—In driving the piles for the foundations of a large building, the penetration is $\frac{1}{2}$ inch under the last blow of the drop hammer, which weighs 1 ton. What will be the allowable bearing value of the pile, figured according to the formula just given, provided the hammer falls 15 feet?

SOLUTION.—In the formula, the safe bearing value of the pile is $W = \frac{2PH}{a+1}$, and, by substitution, $W = \frac{2 \times 1 \times 15}{.5+1} = 20$ T. Ans.

EXAMPLES FOR PRACTICE

1. What will be the safe bearing value of a wooden pile that has a penetration of 1 inch under the last blow of a $1\frac{1}{2}$-ton hammer, the fall of the hammer being 12 feet? Ans. 18 T.

2. A pile driven through stiff clay has a penetration of 2 inches under the last blow of a hammer weighing 1,000 pounds and falling through a distance of 14 feet. What will be the allowable bearing value of the pile? Ans. 4.7 T.

91. Municipal Regulations Regarding Piling. The building ordinances of the city of Chicago require that where wooden pile foundations are used, auger borings of the soil may be required to determine the position of underlying stratum of hard clay or rock; also, that the piles shall be sawed off to a uniform level at least 1 foot below the level of low water and that the heads of the piles be embedded in concrete, or covered with a grillage. This grillage must be proportioned so that the load on each pile shall be not more than prescribed in the law. The top of the timber grillage shall be at least 1 foot below water level. The center of gravity of the pile foundation shall coincide with the center of gravity of the load which it supports. No pile of less than 6 inches diameter at the small end shall be used. The maximum load on a timber pile shall not exceed 50,000 pounds. The allowable compression on concrete piles shall not exceed 400 pounds per square inch. Before concrete piles can be used, test piles must be driven under the direction of the Commissioner of Buildings. The pressure of 400 pounds per square inch cannot be exceeded, as this is the safe strength of the concrete in resisting pressure.

FOUNDATIONS

INTRODUCTION

1. Definitions.—The term **foundations** is applied in a general way to the soil upon which a structure rests, also to the footings, to piles and caissons, and to foundation walls.

The following definitions will be adopted for certain portions of the foundations:

The **foundation bed** is the natural soil on which a structure rests.

The **foundation walls and piers** are the walls and piers built below the curb level or grade or below the tier of floorbeams nearest to the curb level or grade, for the purpose of supporting the walls, piers, and columns of the upper stories of the building.

A **footing** is a spreading course at the base of a foundation wall, pier, or column, to distribute the weight of the structure over a large area of the soil so that there shall be no settlement of the building due to the compression of the soil.

2. Theory of Foundations.—The architect or engineer, in designing a building, estimates the loads that must be supported by the walls and piers, also the weight of the walls and piers themselves, and ascertains the total load that will be transmitted by them to the foundation bed. He also ascertains the weight, per square foot of surface, that the soil will support with safety. His problem is then to adjust the load at the bottom of the wall to the bearing capacity of the soil.

There are two general conditions that will require different treatments. The first condition is when the soil is firm and

COPYRIGHTED BY INTERNATIONAL TEXTBOOK COMPANY. ALL RIGHTS RESERVED

hard and the adjustment can be made by increasing the size of the lower portion of the wall or pier, until the pressure per square foot upon the soil does not exceed the safe bearing capacity of the soil, thus forming a *footing.*

The second condition is when the soil is soft or compressible and the foundation walls cannot be spread so as to bear upon enough soil to safely support the building. It then becomes necessary to penetrate the soft stratum of soil and support the building on a firmer stratum that may underlie the surface stratum. When such a firm stratum is found within a reasonable distance of the surface, piles or caissons are used to transmit the load to this stratum. When there is no firm stratum near the surface, the building must be supported on piles. From the fact that such foundations are generally carried down into the ground for some depth, they are called *deep foundations.*

3. It will be seen that it is necessary, in designing foundations, to know the weights of all the materials used in the construction of a building and the loads to be supported by the floors and roof of the building, also to be familiar with the bearing strength of the soil upon which the building is to rest.

The building laws of large cities, in which most heavy buildings are erected, specify the weights and strengths that are to be assumed for materials, also the floor loads to be used in designing the various types of buildings. They also give the maximum loads that may be placed upon soils of different kinds. When designing the foundations of buildings that are to erected in such cities, the building laws should be carefully consulted.

4. The design of the foundations of a building is a matter of great importance. If the building is heavier than the soil can bear, there will be settlements which may result in cracking the walls or even in the destruction of the building. The same results will happen if the pressure on the soil under one portion of a building is greater than the pressure under another portion. Where very heavy buildings are built on compressible soils there is sure to be some settlement, and the architect or engineer should so design the foundations that the settlement will be *uniform* at all points of the foundation.

Tall buildings frequently settle as much as 3 or 4 inches before coming to rest. This does no harm provided the building settles equally in all parts. If a building settles more in one part than another, the walls will crack and the floors be thrown out of level. Instances have occurred where a portion of a building has settled badly, and it has been necessary to provide new foundations under that portion in order to prevent further settlement. Such operations are very expensive and should be avoided by obtaining an exact knowledge of the conditions and by careful design before the erection of the building is begun. It is therefore of extreme importance, where the soil is compressible, that the footings be so proportioned that when a building settles, it will settle equally in all parts of the foundations.

5. It is generally advisable for an architect having a large building to design, especially where the soil is compressible, to engage a competent engineer to design the foundations of the building. For large buildings of skeleton construction this is commonly done, and the engineer also designs the steel frame of the building. Designing these features of buildings has become a separate and special branch of engineering and for such work architects as a rule employ engineers who make a specialty of it.

6. Types of Foundations.—Two general types of foundations have been mentioned, which are designed to meet different conditions existing in the foundation beds.

The first type is the *footing,* which is used when the foundation bed has sufficient bearing strength to support the structure upon its surface.

The second type is the *deep foundation,* which is used when the upper stratum of soil is too soft to support the weight of the structure even when the weight is spread over a large surface. This type of foundation is formed of piles or caissons, which in most cases are sunk through the upper soft stratum of soil to a firmer stratum below that has sufficient bearing strength to support the load; or piles alone are used when no firm stratum is found.

FOOTINGS

7. The Principle of Footings.—If a man stands on a very soft soil, he will sink to a greater or less depth, according to his weight. If, however, he stands on a plank or wooden platform which rests on this soil, his weight will be distributed over a large area and he will not sink. This illustrates the principle of footings. The platform in this case represents the footing of the wall or column.

8. Purposes of Footings.—The footing, as has been already stated, is a spreading course or platform, formed at the base of a wall, pier, or column to spread the load carried by the wall, pier, or column over a sufficient area of the soil, so that the soil will not sink or settle under the load.

Where the soil, or foundation bed, is of hard material and will support a large load, the footings may be made small. If, however, the foundation bed is a soft soil of small bearing capacity, it will be necessary to spread the footings over a considerable area.

9. In addition to preventing the building from settling, the footings also add to the stability of the walls, especially of thin walls such as are used for small buildings, by providing a broad base upon which these walls can stand.

These footings should be at least 12 inches wider than the thickness of the foundation walls, and of sufficient thickness and area to carry safely the load to be imposed upon them.

PREPARATION OF FOUNDATION BEDS

10. Foundations on Rock.—Before discussing the design of footings, the subject of preparing foundation beds in various kinds of soil will be considered.

The preparation of a foundation bed on rock is generally a simple matter, involving only manual labor. When a structure rests on rock it is not usually considered necessary to excavate deeper than may be needful to remove disintegrated or decayed rock, and to dress the surface to an approximately horizontal plane that will support the base of the wall. In cases where the rock is sloping, it is sometimes necessary to dress it off in a series of horizontal planes in order that the building may not slide off. Fissures, holes, and other irregularities in the rock can be filled with concrete.

Thus in Fig. 1 the line *a b c d* represents the natural profile of the rock upon which it is necessary to place footings. The horizontal planes *e f, g h,* and *m n* are cut in the rock to afford level bearings for the wall. To avoid cutting more rock than is absolutely necessary, the pit, or cavity, *o* can be filled with concrete, or can be bridged over by a reinforced-concrete beam *j,* or by an arch as shown by the dotted lines. The small cavities at *l* and *k* can easily be filled with concrete, beneath the walls. This treatment will produce a perfectly safe and satisfactory foundation bed. The planes *e f, g h,* and *m n* need not be absolutely level but may have a slight slope providing the surface is left rough, so that the footings will not slide. As shown in the figure, all parts of the walls of the building will be supported by the solid rock so that no part of the wall can settle.

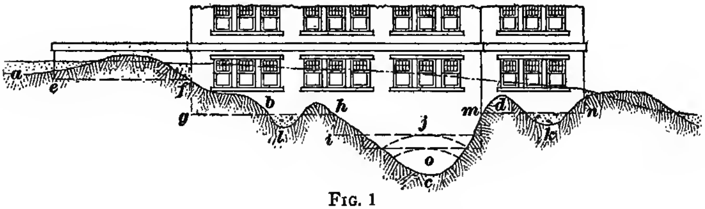


Fig. 1

11. Foundations on Rock and Compressible Soils. It sometimes happens that the foundation bed is formed partly of rock and partly of compressible soil, as illustrated in Fig. 2, in which *a b* represents the natural surface of the ground and *c d* the natural surface of the rock. The footings of the walls of the building are shown at *e f,* resting partly on the rock and partly on the soil. In such a case the footings on the rock will not settle while those on the soil are apt to settle somewhat and cause the wall to crack at *g h*. There are two methods that may be used to overcome this settlement. One is to carry the footings down to the solid rock *h d*, which will have to be leveled off to receive them as indicated by the lines *i j* and *k l*. Another method is to make the footings from *h* to *f* wider than footings *e h* so as to reduce the pressure of the footings on the soil. The New York building laws require that in such a case the footings from *h* to *f* shall be made twice as wide as would be necessary if the building were supported entirely on the soil. This is done so that there will be practically no settlement of the building on the compressible soil.

12. Foundations on Firm Soils.—In preparing foundation beds on firm earth, the material should be excavated to at least a sufficient depth to guard against the action of frost. This depth varies with the locality and climate. Where severe cold is encountered, it is often necessary to excavate from 4 to 6 feet below the surface of the ground, while in climates where freezing does not occur it is necessary to excavate only to firm soil.

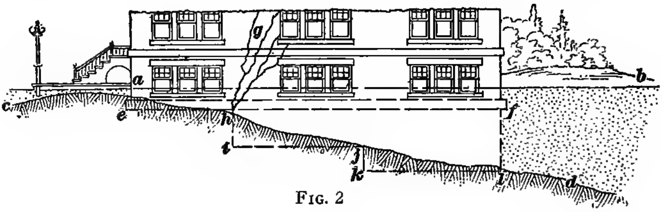


FIG. 2

13. Foundations on Wet Soils.—It is sometimes possible to use a spread foundation on a wet or soft soil, and in some cases the entire site of the building is covered with a *raft* or footing so constructed that the building will float, as it were, upon it. The better method is, however, to use deep foundations in such cases.

14. Foundations on Sloping Ground.—Footing courses built on slopes—especially of clay—are always likely to slide. This may be avoided by cutting horizontal steps in the slope as shown in Fig. 3, where the slope *e f* is stepped off, as shown at *a a*, in order that the footings *b b* may have a horizontal bearing. These footings may be of either stone or concrete, but when stone is used, great care must be exercised to secure a perfect bond at the stepping places, and the foundations should be laid in as long sections as possible.

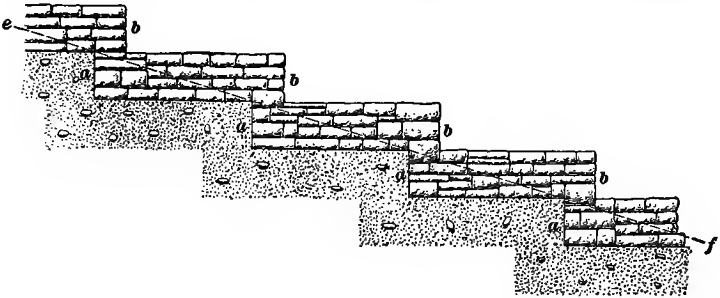


FIG. 3

DESIGN OF FOOTINGS

LOADS SUPPORTED BY FOOTINGS

15. The first step to be taken in designing footings is to ascertain the load that is to be supported by them. This load is considered under three headings. First, the *dead load,* which consists of the weight of the completed building. Second, the *live load,* which includes the weight of the occupants, furniture, machinery, goods, and any other material that may be placed in the building. The weight of the snow which may be supported on the roof is also considered as part of the live load. Third, the *wind load,* which is the load that may be brought upon any part of the footings by the wind blowing against the building.

16. The Dead Load.—The dead load consists of the weight of the walls, floors, partitions, roof, and all other permanent parts of a building. The floors, roofs, and partitions are generally measured by the square foot and the weight is obtained by multiplying the total number of square feet by the known weight of 1 square foot.

Masonry is measured by the cubic foot and the weight is determined by multiplying the total number of cubic feet by the known weight of 1 cubic foot. Table I gives the weights per cubic foot of various kinds of masonry, also of a few woods.

TABLE I

WEIGHTS PER CUBIC FOOT OF VARIOUS BUILDING MATERIALS ACCORDING TO THE BUILDING CODES

Materials	Pounds per Cubic Foot				
	New York City	Denver	San Francisco	Memphis	Ordinary Practice
Common brickwork, cement mortar	120	130			130
Common brickwork, lime mortar	120	120			120
Common brickwork, average	120	125	125	120	125
Pressed brickwork, fine joints	120				140
Concrete, Stone, 1-3-6 mixture	144		145	150	144
Concrete, Cinder, for floor slabs	108		100		110
Concrete, Cinder, for filling	60				60
Granite masonry, Rubble				150	150
Granite masonry, Dressed	168		165		165
Limestone masonry, Rubble				150	150
Limestone masonry, Dressed	156				165
Sandstone masonry, Rubble				150	145
Sandstone masonry, Dressed	144	160	156		160
Terra-cotta masonry		100	100		112
Bluestone	168				
Marble	168				
Oak and long-leaf pine	48				
Spruce, fir, hemlock, white pine	30				

The building codes of various cities give allowable weights per cubic foot for different materials and, where buildings are designed to be erected in such localities, these weights must be used in estimating the weights of buildings. Table I gives examples of such allowable weights.

17. Table II gives the approximate weights of a few typical floor constructions. The loads given are the dead loads only of the floor constructions themselves and do not include any loads upon the floors. In estimating the weights of floors it is customary to find the weight of 1 square foot of floor area, and multiply by the total area of the floor.

18. **Live Loads.**—The live load consists of the weight of people, furniture, stocks of merchandise, machinery, and other materials that may be placed in the completed building. This load is variable and uncertain and it is impossible to determine it accurately.

TABLE II

WEIGHTS PER SQUARE FOOT OF FLOOR AREA OF DIFFERENT TYPES OF FLOOR CONSTRUCTION

Type of Floor	Weight per Square Foot Pounds
Floors for dwellings, wood construction, light...	12 to 17
Floors for dwellings, wood construction, heavy..	14 to 20
Floors for mills, wood construction.............	20
Fireproof—Concrete slabs, wooden flooring.....	60 to 90
Fireproof—Terra-cotta arches, wooden flooring..	50 to 70

The live loads that are supported on the floors of various classes of buildings have been determined approximately by experiment, and the building codes of different cities specify the live loads that the floors of buildings of various classes must be able to support safely. Table III gives the live loads per square foot to be used in designing floors for various buildings. These loads are the *maximum live loads,* or the *full live loads,* that are allowable on the floors for which they are specified.

19. The weights shown in the table in the column headed "Experiment" are the results of certain tests made with the view of ascertaining the actual loads which occur in the various

TABLE III

SAFE LIVE LOADS ON FLOORS PER SQUARE FOOT OF SURFACE, IN POUNDS

Purpose of Building	Experiment	New York 1916	Chicago 1912	San Francisco, 1915	Boston 1912	Indianapolis 1904	Pittsburgh 1918
Dwellings, apartments	20 to 40	40	40	60	50	50	40
Hotels	20 to 40	40	50	60	50	50	70
Office buildings	16 to 33	60	50	60	100	75	70
Churches	15 to 25	100	100			125	100
Ball rooms		100	100	125	200	125	150
Theaters	44	100	100	75		125	100
Schools	15 to 25	75	75	75	60	100 to 200	70
Hospitals			50	60		50	70
Factories		120 up			125	120	125
Stores	50 to 80	120 up	100	125 to 250	125	100 to 200	100
Warehouses		120 up	100		250	100 to 200	100 to 150
Sidewalks				150		300	
Roofs		40	25	20 to 30	40	30	40

types of buildings. It will be noted that these actual loads are smaller than those given in the other columns, which are those required by the building codes of various cities. It will also be observed that the requirements for the same class of buildings vary in different cities. For instance, floors of school buildings must be designed to support a live load of from 100 to 200 pounds per square foot in Indianapolis, while for Boston they need be designed for only 60 pounds. These variations are due to differences in judgment on the part of the authorities in different cities. Because of these differences, when designing buildings to be erected in cities, the building codes must be carefully consulted and their specifications followed.

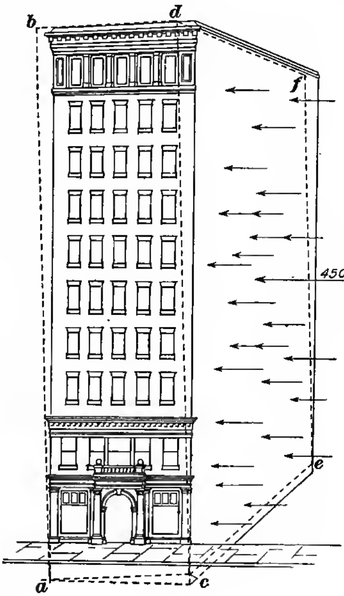


FIG. 4

20. The Wind Load.—A strong wind blowing against a tall building will exert a very decided effect upon the foundations of the building. Thus, in Fig. 4, the wind blowing strongly against the tall building would have a *tendency* to tip the building as indicated by the dotted lines. While the building would not be actually blown over, or even moved perceptibly, an increased pressure will be brought to bear on the footings under the wall *a b* which is opposite the wall upon which the wind is blowing. At the same time there will be a *tendency* on the part of the wall *c d f e* to rise and thus take some of the pressure off the footing *c e*.

21. Estimated Strength of the Wind Pressure.—It is estimated that the maximum pressure that can be exerted against a wall surface by the wind is about 30 pounds per square foot. The building laws of New York City, Boston, and Indianapolis require that a pressure of 30 pounds per square foot shall be used in calculating the effect of wind pressure on the footings of buildings. Chicago requires that a pressure of 20 pounds per square foot be used in such calculations.

The pressure is considered as being exerted at the middle of the height of the wall, as indicated by the arrow *g*. In the structure shown in Fig. 4, the area of the wall *c d f e* is 100 ×150 = 15,000 square feet. At 30 pounds per square foot the total wind pressure against the wall will be 15,000×30 = 450,000 pounds, or 225 tons. This is a considerable pressure and is bound to have an effect upon the stability of the building.

The effect of the wind pressure is greatest in a very tall building on a narrow lot, or when the height *c d* is considerable and the width *a c* is small.

When the height of a building is less than 100 feet and the width is not less than one-fourth the height, the effect of the wind upon the footings may be neglected. As the effect of the wind upon tall buildings is a matter that is left to engineers to calculate, it will not be considered any further in this paper.

22. Allowable Reductions in Loads on Footings. The dead load is a fixed load and the whole of it must be supported on the footings. In a new building, before it is occupied, the dead load constitutes the entire load upon the footings, excepting a possible wind load.

As has been said, the live load is variable and cannot be accurately calculated. There may be a great many people in a building at one time and none at another. One room may be filled with heavy furniture and another contain very little. A warehouse at one time may be packed with merchandise and at another time may be quite empty.

While the building codes of various cities require that the floors and roof be designed so as to support certain maximum live loads per square foot of surface, it is highly improbable that all the floors and the roof will carry this maximum load at the same time. It is equally improbable that the footings will at any time support the sum of all these maximum live loads upon all the floors. Many building codes recognize this fact and provide for certain reductions in the loads on the vertical supports of buildings.

23. The building code of New York City makes the following provisions regarding reduced loads on footings:

> *Loads on Vertical Supports.*—Every column, post, or other vertical support shall be of sufficient strength to bear safely the combined live and dead loads of such portions of each and every floor as depend upon it for support, except that in buildings more than five stories in height the live load on the floor next below the top floor may be assumed at 95 per cent. of the allowable live load, on the next lower floor at 90 per cent., and on each succeeding lower floor at correspondingly decreasing percentages, provided that in no case shall less than 50 per cent. of the allowable live load be assumed.
>
> *Pressure Under Footings.*—For the loads exerting pressure under the footings of foundations the full dead loads and the figured live loads on the lowest tier of columns, piers, or walls shall be taken.

In other words, the footings shall be figured for the full dead loads and the reduced live loads.

24. This reduction in the amount of the required live loads permits of reducing the sizes of the columns and the footings. The thicknesses of the walls are not affected, but are determined according to their heights. Table IV shows the maximum live loads according to the New York City building code, also the reduced loads for a sixteen-story office building in accordance with the foregoing quotation.

This table shows that while the maximum live load on all the floors of the building for 1 square foot of the building is 1,060 pounds, the lowest tier of columns and the footings need be designed to support only 715 pounds of live load in addition to the total dead load. This saving is about one-third of the live load.

25. It should be understood that each column supports a given floor area and the load coming on each column will depend on the extent of this area multiplied by the live load in pounds per square foot of floor. Each column carries not only this load, but also the loads transmitted directly from the column above. Thus, the column on the fourteenth floor supports also two other columns above with all their dead and live loads.

TABLE IV

EXAMPLE OF REDUCED LIVE LOADS FOR A 16-STORY OFFICE BUILDING ACCORDING TO THE NEW YORK CITY BUILDING CODE

Floor	Maximum Live Loads as per Table III Pounds per Square Foot	Allowable Percentage of Maximum Live Load	Net Reduced Live Load on Columns and Walls Pounds per Square Foot
Roof	40	100	40
16	60	100	60
15	60	95	57
14	60	90	54
13	60	85	51
12	60	80	48
11	60	75	45
10	60	70	42
9	60	65	39
8	60	60	36
7	60	55	33
6	60	50	30
5	60	50	30
4	60	50	30
3	60	50	30
2	60	50	30
1	120*	50	60
Total	1,060		715

* If used for a store.

26. The building codes of Chicago, San Francisco, and other large cities permit of reductions similar to those allowed by the New York code, in the amount of the live load that

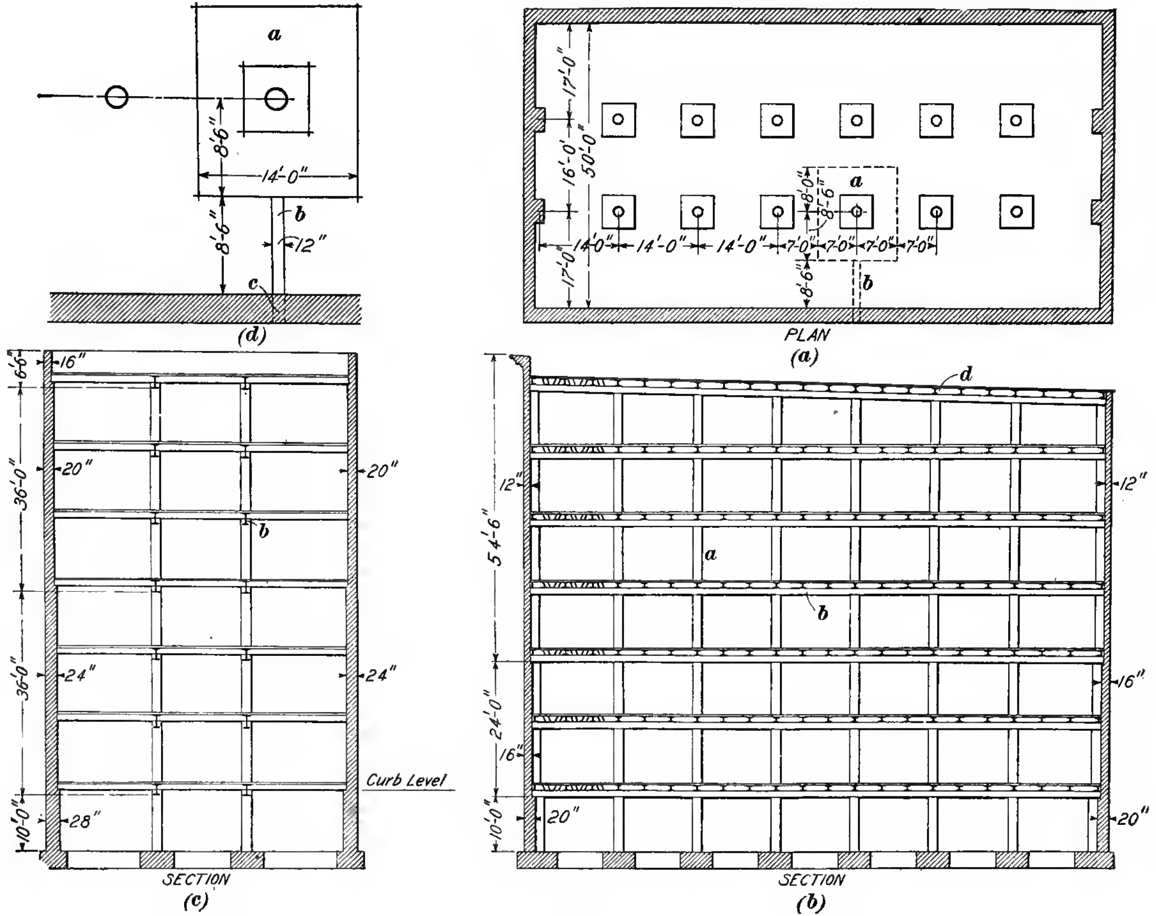

a
8'-6"
14'-0"
8'-6"
b
12"
c
(d)
17'-0"
16'-0"
50'-0"
17'-0"
14'-0"
14'-0"
14'-0"
7'-0"
7'-0"
7'-0"
7'-0"
8'-0"
8'-6"
8'-6"
a
b
PLAN
(a)
6'-6"
16"
36'-0"
20"
20"
b
36'-0"
24"
24"
Curb Level
10'-0"
28"
SECTION
(c)
d
54'-6"
12"
12"
a
b
24'-0"
16"
16"
10'-0"
20"
20"
SECTION
(b)

Fig. 5

must be used in estimating the loads supported by vertical supports.

27. These building codes also require that the footings shall be made large enough to distribute properly the loads coming on the lowest tier of columns and the corresponding parts of the walls and piers.

28. Calculation of Size of Footings.—The method of calculating the loads to be supported, and from them the size of the footings required, is illustrated by the following calculations for the footings of the building shown in Fig. 5.

In this calculation it is assumed that the building is to be built according to the building code of the city of New York, which has been quoted in Art. **23** and in Table III.

The dead load on the roof will be 60 pounds per square foot. The dead load on the floors will be 75 pounds per square foot. The live load on the roof is 40 pounds and on the floors 60 pounds per square foot. The weight of brickwork is 120 pounds per cubic foot. It is assumed that a vertical line of columns with the necessary fireproofing will weigh 10,000 pounds, and that the safe bearing value of the soil is 5,000 pounds per square foot.

29. In calculating the size of the footings under the side wall, it will be necessary to calculate the weight supported by only 1 foot of length of the wall. One linear foot of wall supports a floor area of 1 ft.×8½ ft. on each floor. This area is shown in Fig. 5 at *b* in view (*d*), which is an enlarged portion of the plan (*a*). The dimension 8½ feet is one-half the span between the center of the column and the inside of the wall. The load on the wall footing is then the sum of the loads on this area on all the floors and the roof (the live load being reduced according to Art. **24**) plus the weight of the wall itself.

The thickness of the wall in its various parts is obtained from the section, Fig. 5 (*c*). In the calculation, the inches are reduced to fractions of a foot.

The load on 1 linear foot of wall footing is calculated as follows:

Dead Loads		Pounds
Weight of brickwork	6½×1⅓× 1×120=1,040.0	
	36 ×1⅔× 1×120=7,200.0	
	36 ×2 × 1×120=8,640.0	
	10 ×2⅓× 1×120=2,800.0	
Dead load—floors	1 ×8½×75× 6=3,825.0	
Dead load—roof	1 ×8½×60× 1= 510.0	
Total dead load		24,015.0
Live Loads on Floors and Roof, Reduced as per Art. **24**		
Roof	40×8½×1.00= 340.0	
6th floor	60×8½×1.00= 510.0	
5th floor	60×8½× .95= 484.5	
4th floor	60×8½× .90= 459.0	
3d floor	60×8½× .85= 433.5	
2d floor	60×8½× .80= 408.0	
1st floor	60×8½× .75= 382.5	
Total live load		3,017.5
Total load		27,032.5

Since the safe bearing value of the soil is 5,000 pounds per square foot, the area of the footing must be 27,032.5÷5,000=5.4 square feet for each linear foot of wall.

30. The load supported by the footing under a vertical line of columns *a*, in view (*a*), will be the dead and the live loads on an area of 16½ ft.×14 ft., or 231 square feet, on each floor and the roof (the live load reduced as per Art. **24**) plus the weight of the columns. The load is calculated as follows:

Dead Load		Pounds
Weight of the columns	10,000	
Dead load on columns:		
Roof, 231×60×1	13,860	
Floors, 231×75×6	103,950	
Total dead load		127,810
Live Load on Columns		
Roof	40×231×1.00= 9,240	
6th floor	60×231×1.00= 13,860	
5th floor	60×231× .95= 13,167	
4th floor	60×231× .90= 12,474	
3d floor	60×231× .85= 11,781	
2d floor	60×231× .80= 11,088	
1st floor	60×231× .75= 10,395	
Total live load		82,005
Total load		209,815

The area of the footing of the column is 209,815÷5,000=41.963, or 42 sq. ft.=6½ ft.×6½ ft., approximately.

Footings of this size will be acceptable to the Bureau of Buildings of the city of New York.

31. An analysis of the loads that may come upon the footings in the building shown in Fig. 5 is given in Table V, which shows the loads on the foundation bed under three different conditions. Load 1 consists of the load on the foundation bed when the building is supporting the dead loads and the maximum live loads. Load 2 is made up of the loads as given in the preceding articles. Load 3 is the load when the building is newly built and has not received any live load.

TABLE V
LOADS ON FOOTINGS UNDER DIFFERENT CONDITIONS

Loads Supported	Under 1 Ft. of Wall	Under Column
1. Dead load + full live load....	27,415.0	220,210
2. Dead load + reduced live load	27,032.5	209,815
3. Dead load + no live load....	24,015.0	127,810

The footing area that would be required under the column when the building is empty, as in load 3, would be 127,810 ÷5,000=25.56 square feet. If the building should be fully loaded, as with load 1, the footing area required would be 220,210÷5,000=44 square feet.

PROPORTIONING OF FOOTINGS

32. Equalizing Pressures Under Footings.—Table V shows that when the conditions existing with load 3 are changed to those of load 1, not only is the load increased but an increased proportion of it is borne by the columns as compared with the part borne by the wall. As a matter of safety, it is desirable to provide for the possibility of the building being loaded with its maximum load. It is also advisable to proportion the size of the footings so that the pressure per square foot shall be the same under both the wall and the columns.

To attain these conditions in the building under consideration, where the maximum load on the soil is to be 5,000 pounds per square foot, the area of the footing under a column would be made 220,210÷5,000=44 square feet. If the reduced load, as load 2 in Table V, is to be used in designing the building, the footings for the columns should nevertheless be of the size just found but the footing of the wall should be so proportioned that the pressure due to the reduced load will be the same per square foot under the column footing and the wall footing. In Table V, the reduced load is shown to be 209,815 pounds. Then the pressure under column will be 209,815÷44 =4,769 pounds per square foot. By dividing the reduced load under the wall, 27,032.5, by 4,769, the size of the footing under the wall is found to be 5.67 square feet for each 1 foot of the wall, or 5 feet 8 inches in width.

By so proportioning the footings, the pressure on the soil under probable conditions will be equal under both wall and column, and yet will never exceed the safe bearing value of the soil. Under these conditions there is little likelihood of inequality of settlement.

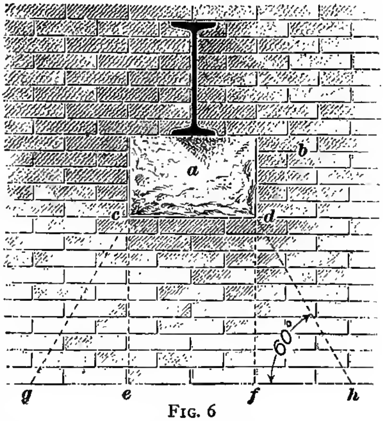


FIG. 6

DISTRIBUTION OF LOADS

33. Distribution of Loads in Walls.—A heavy concentrated load *a*, Fig. 6, bearing upon a wall *b* will not be transmitted directly down through a portion of the wall *c d f e*, but will spread, as indicated at *c d h g*. This is due to the lapping of the bricks or stones over each other. It is also true in a monolithic wall such as a concrete wall, which is tied together by the adhesion of its particles. The angle at which such a load spreads cannot be determined, but may be assumed to be as shown in the figure by the lines *c g* and *d h*, which are at an angle of 60 degrees to the horizontal line *g h*.

34. Distribution of Loads on Footings.—As shown in Fig. 7, the load of the wall *a* presses down on the footing *b*

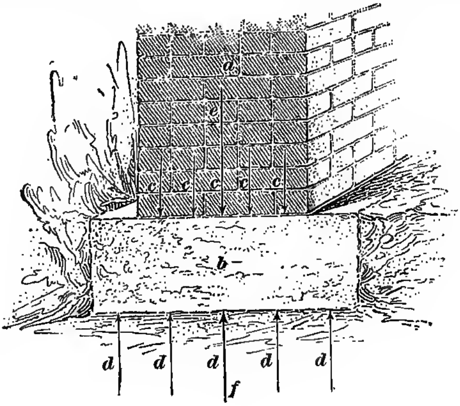


Fig. 7

as indicated by the arrows *c*. The earth resists this pressure, as indicated by the arrows *d*. When the footing extends equally on each side of the wall the center of pressure *e* of the wall is opposite the center of the upward pressure *f* of the earth, the pressure on the soil is practically uniform, and the loading is ideal.

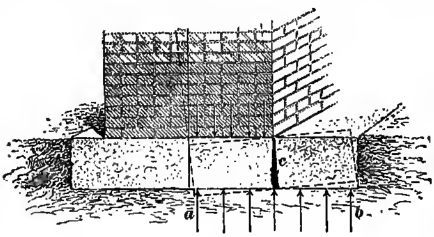


Fig. 8

In Fig. 8 is shown a case which frequently happens in cities where the walls are built right up to the lines of the property and where it is impossible to extend the footings over on the adjacent property. All the necessary spreading of the footings must therefore be done on the lot upon which the building is erected. This produces a condition such as shown in the figure, where the center of pressure of the wall is not opposite the center of upward pressure of the earth. In this case there will be a tendency for the footing to settle more at *a* than at *b*, as indicated by the dotted lines; or the projecting part of the footing may break off at *c*.

A method of preventing this inequality of settlement is to increase gradually the thickness of the wall, as shown in Fig. 9, so as to distribute the weight of the wall over the entire footing and bring the centers of pressure as nearly opposite each other as possible. In cases such as have just been considered, there is a tendency for the walls to settle and bend outwards as indicated in Fig. 8. This can be neutralized by anchoring the floorbeams into the wall, as shown in Fig. 9 at *a*. This process serves to tie the walls together and prevent their spreading.

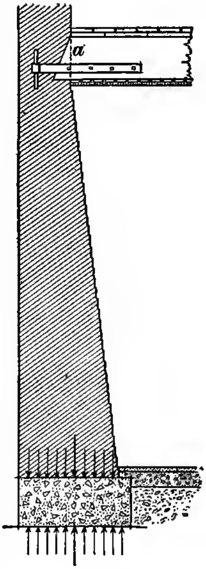


Fig. 9

EXAMPLES OF FOOTINGS

ORDINARY FOOTINGS

35. Footings of Stone.—A very simple form of footing made of stone is shown in Fig. 10. Footings of this kind are used in dwellings and other small buildings and are formed of large flat stones not less than 8 inches in thickness, as shown at *a*. These stones should be at least 12 inches wider than the thickness of the wall *b*, and should be carefully *bedded*, or set on the foundation bed so that they will bear on the soil at all points. A bed of mortar *d* is sometimes placed under such stones to insure an even bearing on the soil. Another method that is sometimes used to obtain such a bearing is to place sand against the sides of the footing stone and play the hose upon it, thus washing the sand into all the voids or openings between the soil and the stone and forming a solid bearing for the stone.

The footing stones should be of sufficient thickness so that the projecting parts *c* will not break off. If the stone is a very hard stone, its thickness should be about one-third its width. If the stone is comparatively soft, its thickness should be about one-half its width.

36. Footings of Concrete.—A simple footing made of concrete is shown in Fig. 11. For all footings of this character concrete is the best material to use, as it is easily handled, can be made of any desired size, and forms a perfect contact with the foundation bed, thus assuring an even bearing on the soil.

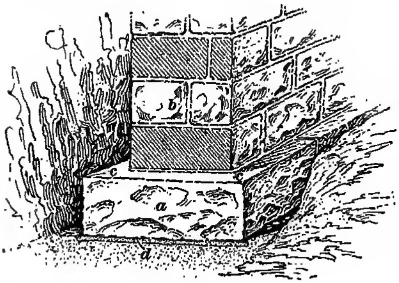


Fig. 10

Where the soil is firm enough, trenches for concrete footings are dug with the sides vertical, as at *a*, so as to act as forms for the concrete when it is poured into the trench.

When the concrete has been deposited it is tamped in place. This tamping or ramming forces the concrete into all parts of the trench and adds to the density of the concrete after it has set.

If the soil is quite soft or sandy so that the sides of the trench cannot be formed of earth, it becomes necessary to use wooden forms to receive the concrete, as shown at *b*.

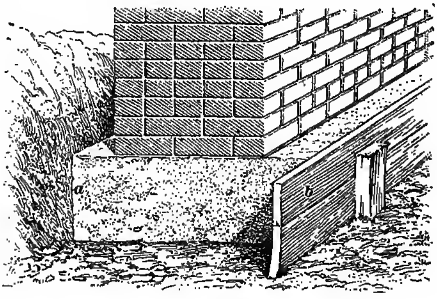


Fig. 11

Concrete for footings should be composed of 1 part Portland cement and not more than 2½ parts of sand and 5 parts of broken stone or gravel. The gravel should be well washed and the stone should be broken to such a size as will pass through a 2-inch ring. In localities where stone is not easily obtained, broken brick or terra cotta may be used in the same proportion as stone, care being taken to use good hard-burned material. The concrete should be mixed wet, so that it will have a consistency like jelly, and will flow into all parts of the form or trench. The concrete should be poured soon after having been mixed and not be allowed to set before it has been put in place.

The thickness of plain concrete footings should be from one-third to one-half the width of the footing. They should be not less than 12 inches thick except for very light buildings, when the thickness may be 8 or 10 inches.

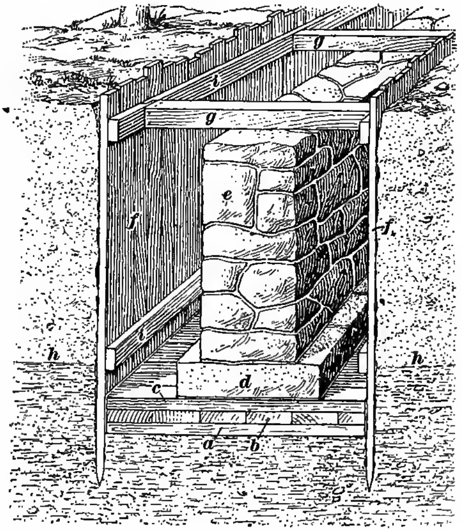


Fig. 12

37. Footings of Timber.—Timber is sometimes used for footings where the buildings to be supported are not very tall and the loads on the footings are not heavy. It is also used for the footings of temporary buildings such as exposition buildings.

Timber footings can be used most successfully in positions where they will be constantly saturated with water, as timber under that condition will never decay and lose its strength. The best timbers to use for footings are long-leaf yellow pine and oak.

When timber cannot be kept wet, artificial means are employed to prevent decay. One of these methods is to coat it with asphalt or tar; another is to saturate the timber with creosote or some other chemical substance that will prevent decay.

38. A method of constructing a timber footing is shown in Fig. 12. A layer of 3″×12″ planks *a* is laid across the trench.

Another layer *b* is placed lengthwise upon the first. A third layer *c* is laid crosswise. Upon this timber footing is laid a stone course *d* which supports the foundation wall *e*.

The sides of the trench, where the soil is soft, are supported by wooden sheet piling *f* which is driven down into the soil by means of a heavy maul or hammer and is held in place by the braces *g* and the pieces *i*.

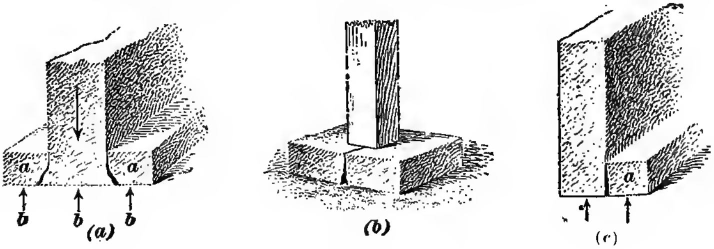
When possible, the timber footings must be placed so as to be below the level *h h* at which water always stands in the soil; otherwise timber must be treated so that it will not decay.

STEPPED FOOTINGS

39. Reason for Stepped Footings.—If the loads on the soil are heavy and the soil is soft, the simple footings just described may not spread sufficiently to cover the necessary area of foundation bed. It is then necessary to make them wider in proportion to the load and to the increased thickness of wall.

Simply to widen the footings so that they will cover sufficient soil, would probably result in the failure of the footings in one of the ways illustrated in Fig. 13.

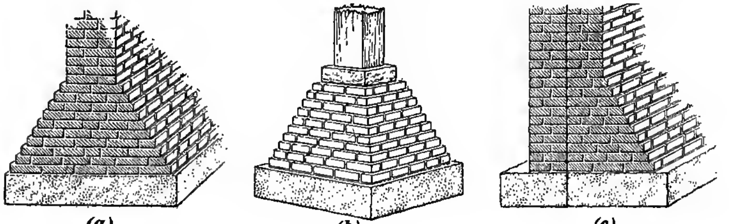
In (*a*) is shown a footing under a wall. The resistance of the earth, as indicated by the arrows *b*, acts as an upward pressure over the entire bottom surface of the footing. The downward pressure on top of the footing is confined to the surface underneath the wall and there is virtually no pressure on the top of the footing at *a a* to counteract the upward pressure of the



(*a*) (*b*) (*c*)

Fig. 13

earth at these points. This arrangement of pressures may result in breaking off the projecting parts *a* of the footing, after which they are of no use in distributing the load from the wall to the foundation bed.



(*a*) (*b*) (*c*)

FIG. 14

In (*b*) is shown a similar result in the case of a post, and at (*c*) is shown a case where the footing has been extended on one side of the wall only and under heavy loading the portion *a* of the footing is likely to break off.

The danger from the causes mentioned is removed by *stepping, or offsetting,* the footings as shown in Fig. 14 or by designing them according to the principles described later under the heading Spread Footings. By stepping the footings as shown in the figure, the loads from the walls, columns, or piers, will be spread gradually so as to act over the entire surface of the footing and not over a portion of the footing only, and thus the resisting pressure of the earth will be balanced.

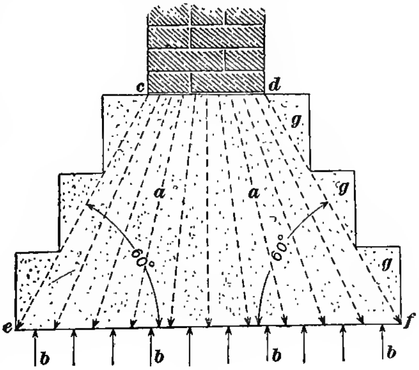


FIG. 15

40. Slope of the Footing.—The angle at which the load will spread from the wall to the footing cannot be accurately determined. When the footing can be extended on both sides of the wall as shown in Fig. 15, the angle of 60 degrees with the horizontal is considered a safe one to use for footings composed of stone or strong concrete. If brick or a weak mixture of concrete is used for stepped footings a steeper slope should be used. The arrows *a* indicate how the load spreads so as to meet the pressure of the earth, which is indicated by the arrows *b*.

The footing should be designed so that the offsets *g* shall be outside the lines *c e* and *d f*. The thickness of the offsets will depend on the nature of the material of which the footings are composed. Stone offsets or steps should be made not less than 8 inches in height. Offsets made of concrete should be made with reference to economy in making the forms. Brick offsets are made of one or two courses or layers of brick.

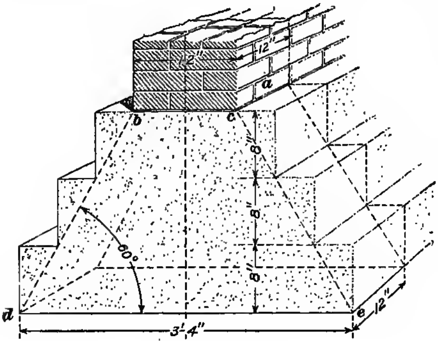


Fig. 16

41. When the footing is stepped on one side only, as shown in Fig. 14 (*c*), the angle of the slope should be steeper than 60 degrees. In such a case it is desirable to carry the stepping as high up as possible.

42. Design of a Stepped Footing of Concrete.—Suppose it is required to design a stepped footing according to the approximate rule just given. The footing is to be made of a strong concrete consisting of 1 part Portland cement, 2½ parts sand, and 5 parts of broken stone. The load on the wall is

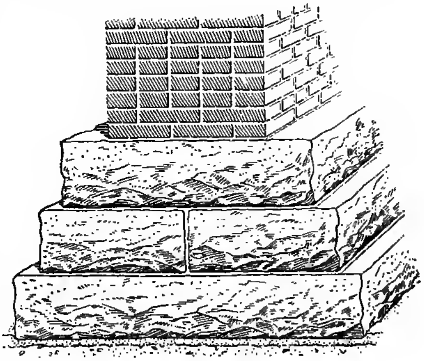


Fig. 17

10 tons per foot of length of the wall and the bearing value of the soil is 3 tons per square foot. The wall is 12 inches in thickness and is situated so that the footing can extend on both sides of the wall.

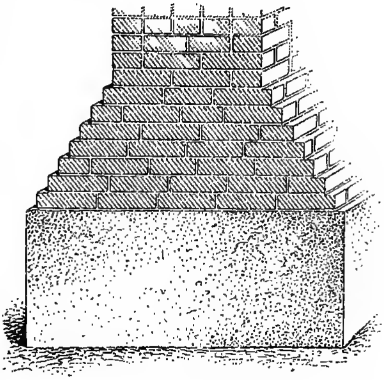


Fig. 18

For 1 foot in length of the wall, the load will be 10 tons. The area of footing required for this load is 10÷3=3⅓ square feet. This area will be required under each running foot of the wall. The footing will therefore have to be 3⅓ feet in width. A section of this wall and footing is shown in Fig. 16, in which *a* is a portion of the wall 1 foot in length. From the points *b* and *c* draw the lines *b d* and *c e* at 60 degrees with any horizontal line, as shown. Where these lines are 3⅓ feet apart, measured horizontally, as at *d e*, will be the bottom line of the footing.

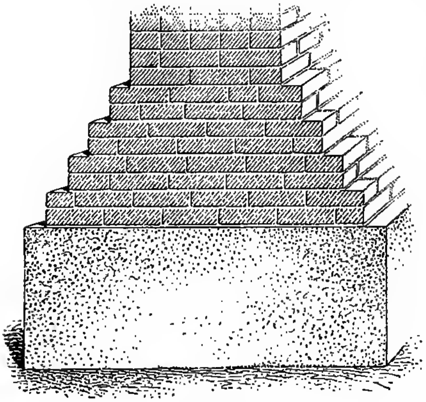


Fig. 19

The height of the footing will be the vertical distance between the lines *b c* and *d e*. In this case the distance or height of the footing is 24 inches. The offsets are made 8 inches in height, which will be economical both in making the forms and in the amount of concrete used.

43. Design of a Stepped Footing of Stone.—If stone were used in the example just given, the footing would consist of three layers of 8-inch-thick stone. The projection of each offset in this case is 4⅝ inches. A stepped footing of stone is shown in Fig. 17. Whenever possible, the bottom layer of stone should be formed of single stones the full width of the trench. This course should be well bedded in cement mortar. The upper layers also should be set in cement mortar. Such a footing as this is more expensive and much more difficult to build than a similar footing of concrete.

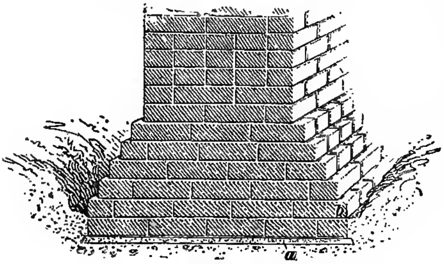


FIG. 20

44. Design of a Stepped Footing of Brick.—Where brick is used, a bottom course of concrete is generally provided. This course is generally made not less than 12 inches in thickness, or height, and the brickwork is gradually diminished in thickness until the thickness of the wall is reached, as shown in Figs. 18 and 19. In Fig. 18 the brickwork is stepped back in every course, while in Fig. 19 it is stepped in every two courses.

In some localities it is customary to use brick footings without a bottom course of either stone or concrete, the brickwork resting directly upon the ground as shown in Fig. 20. Only the hardest kind of brick, such as paving brick, should be used for such a footing. The brick should be laid with their length across the wall so as to thoroughly tie the footing together. The footing should be started on a good bed of cement *a*, and the bottom course of brick should be a double course, as shown at *b*.

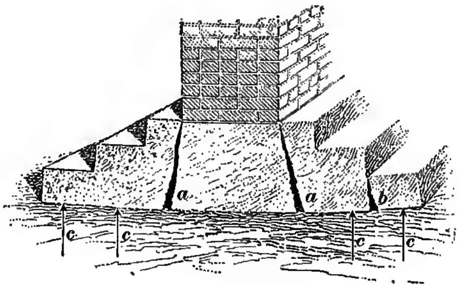


FIG. 21

45. Failure of Stepped Footings.—When, as shown in Fig. 21, stepped footings are built with a slope that is not sufficiently steep, they are likely to fail as indicated at *a* or at *b*, as the upward pressure of the soil at *c* is not resisted by a sufficient downward pressure immediately above.

SPREAD FOOTINGS

46. General.—It will be seen that, if the bearing strength of the soil is small and the loads on the walls or piers are heavy, it will be necessary to spread the footings over a considerable area of the foundation bed. If a stepped footing were used this would make the footing very deep as well as wide and would require considerable labor and material to build it, as well as a large excavation to contain it. A large part of this material, labor, and excavation, as well as of cost, is saved by the use of what are known as *spread footings*.

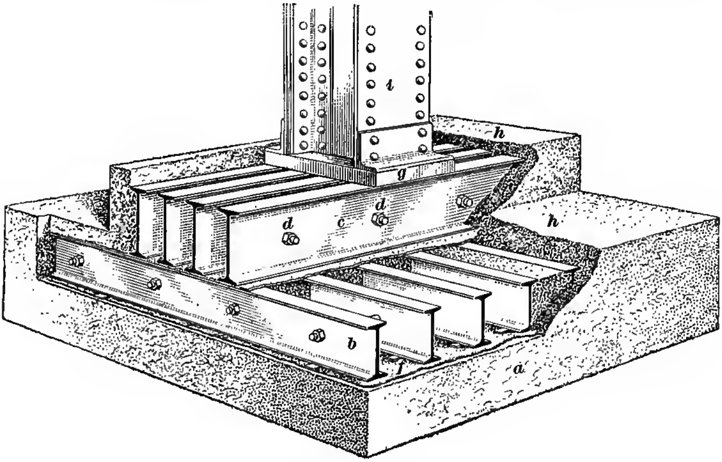
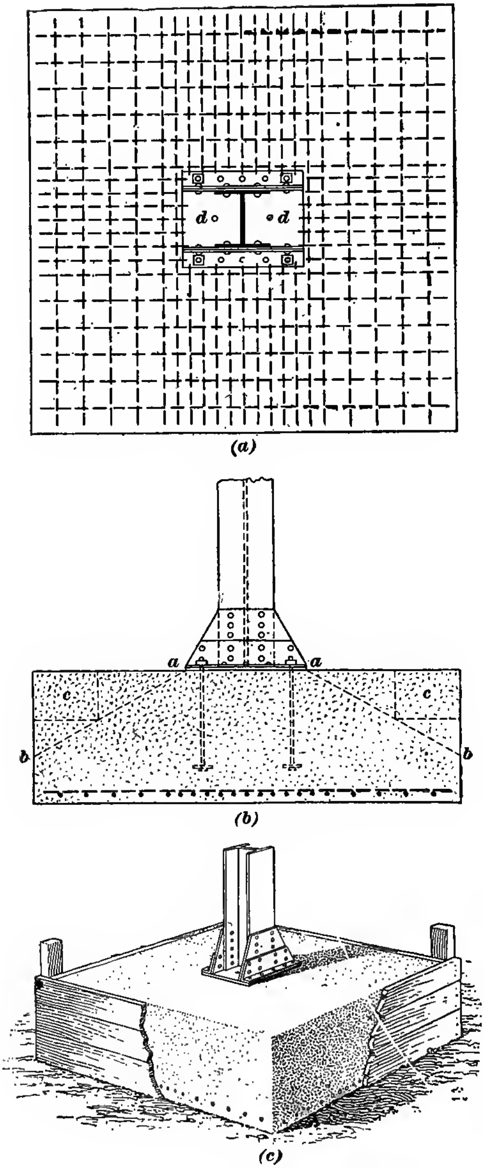


FIG. 22

47. Definitions.—A **spread footing** or **foundation** may be defined as one whose height is small in comparison with its width and which depends upon its action as a beam for its



(a)

(b)

(c)

Fig. 23

strength. The object of the spread foundation is to spread the load over a considerable horizontal area near the surface of the ground. Spread footings are generally made of **I** beams or of reinforced concrete.

A spread footing formed of **I** beams is called a *grillage footing* or an **I**-*beam grillage*. A footing of this type is illustrated in Fig. 22. A reinforced-concrete spread footing is shown in Fig. 23. In this footing, rods of steel are buried near the bottom of a mass of concrete and provide a resistance to pulling which the concrete itself does not possess.

48. Comparison With Stepped Footings.—A comparison between a stepped footing and a spread footing will illustrate the advantages of the latter. In Fig. 24 (*a*) is shown a *stepped footing* and in (*b*) a *spread footing,* each of which is designed to support a load of 200 tons.

It will be noticed that the footing in (*a*) is 4 feet in thickness below the line *a b,* which is the bottom of the base of the column, while the corresponding thickness in (*b*) is only 13 inches.

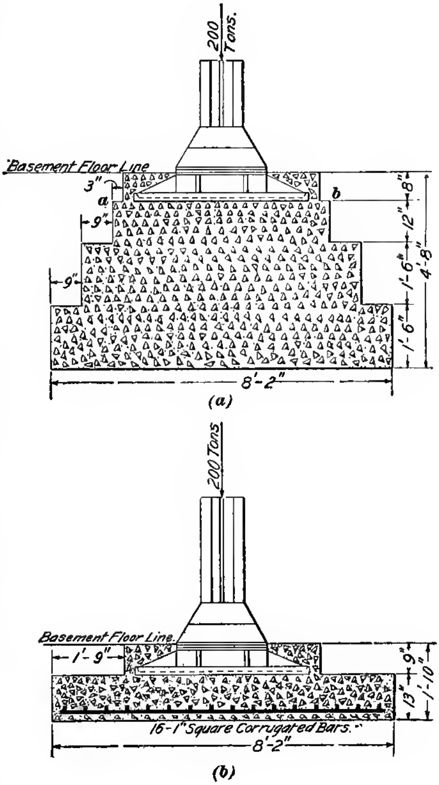


Fig. 24

The excavation required in (*a*) will extend 4 feet 8 inches below the basement floor, while in (*b*) a depth of only 1 foot 10 inches will be required. The amounts of excavation and concrete, also the approximate costs of these footings, are as follows:

Cost of footing (*a*):	
Excavation—11.53 cu. yd. @ 75 cents	$ 8.65
Concrete—202.3 cu. ft. @ 26 cents	52.60
Total cost of footing (*a*)	$61.25
Cost of footing (*b*):	
Excavation—4.53 cu. yd. @ 75 cents	$ 3.40
Concrete—93 cu. ft. @ 26 cents	24.18
Corrugated bars—720 lb. @ 3 cents	21.60
Total cost of footing (*b*)	$49.18

49. Forces Acting in a Spread Footing.—The forces acting in a spread footing are illustrated in Fig. 25. The weight of the wall presses downwards and this force is resisted by the upward pressure of the earth as indicated by the arrows *b*. The earth pressure acts over the entire surface of the footing. The downward pressure acts only over the footing directly beneath the wall and not on the parts *a*. These forces produce a tendency in the footing to bend as shown in the figure. Unless the footing is made strong enough to resist this tendency to bend it may fail as indicated at *f*.

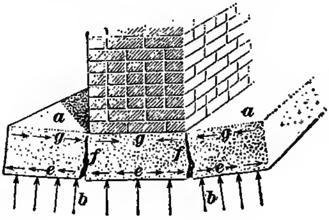


Fig. 25

The forces acting in the footing itself are *tension,* or pulling apart, which occurs in the lower part of the footing and is shown by the arrows *e*; and *compression,* or pushing together, which occurs in the upper part of the footing and is indicated by the arrows *g*.

The concrete itself will successfully resist the compression at *g*, but it has not the strength to resist the tension at *e*. Hence, to supply the needed strength, steel rods or wire mesh are placed near the bottom of the mass of concrete composing the footing.

The concrete must also resist another compressive force caused by the pressure of the foot of the wall upon the upper surface of the footing. Concrete will resist successfully a certain pressure per square inch and if this pressure is not exceeded under the wall the footing will not crush at that point.

50. In the case of a steel grillage footing where **I** beams are used, the **I** beams are particularly adapted by their shapes to take care of the compressive and tensile stresses, as the stresses which occur in a spread footing are practically the same as those that operate in a beam. The upper flange of the **I** beam resists the compression and the lower flange takes care of the tension.

51. In view of the fact that the forces acting in and upon a spread footing are the same as those acting upon a beam of the cantilever type, the formulas for designing beams are applied in designing footings. These formulas are given in the Section on *Design of Beams*.

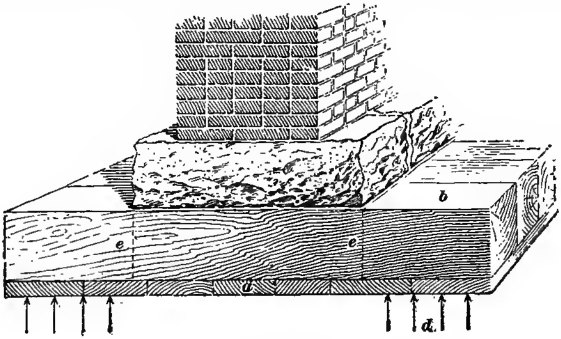


FIG. 26

52. Wooden beams can be used successfully as spread footings when the loads are comparatively light, as wood is well adapted to resisting the compression and tension occurring in such footings. An example of a spread footing made of wood is given in Fig. 26.

53. Spread Footings of Timber.—Fig. 26 shows an example of a timber footing which consists of a layer of timbers *a*, which are laid in the trench lengthwise. On top of this layer is another layer *b* laid crosswise. This layer is much wider than the wall which it supports and the pressure of the earth *d* under the projecting ends of these timbers tends to bend the ends upwards and break them at *e*. This tendency is resisted by fibers of the timber.

54. Spread Footings of Steel Shapes.—Rolled steel **I** beams and railroad rails are particularly well adapted for use in forming shallow spread footings, as they are especially designed to resist the forces to be met with in such footings.

An example of an **I**-beam grillage is shown in Fig. 22. A bed of concrete *a*, which should be about 12 inches thick, is first put in place. This is generally made square under columns or piers, as that shape is the most economical.

Upon this bed of concrete, the first layer of **I** beams *b* is laid in a bed of strong cement mortar *f*, which is used to form a perfect bearing of the beams on the concrete bed. The tops of the beams are all brought to the same level. The beams are spaced or set apart so that there shall be about 3 inches between them. Concrete is then filled in between and around these beams to the tops of the flanges.

In most cases of grillage footings there are two layers of beams, as shown in this illustration. The upper layer *c* is set upon the lower layer in a bed of strong cement mortar, which is from ½ inch to 1 inch in thickness. These beams are also made level at the top and filled around with concrete. The beams are held together by means of separators of cast iron or gas pipe. These separators are placed near the ends of the beams and in intermediate positions not over 5 feet apart, and are secured by bolts *d* which pass through them. A thick slab of solid steel *g*, called a *bolster*, is placed under the column where it rests upon the upper layer of beams, its purpose being to take up any inequalities in the column bearing. The entire footing is buried in concrete as shown at *h*, the concrete extending for at least 3 inches outside of the steel work. The column is shown at *i*.

The concrete used to fill in between the beams should be made in the proportion of 1 part Portland cement, 2 parts sand, and 4 parts of broken stone. The stone should not be larger than will go through a 1½-inch ring.

55. Durability of Steel in Footings.—In footings in which rails and I beams are used, the load is distributed by virtue of the strength of the steel, and the concrete contributes very little strength to the footing. The concrete serves the purpose of providing an even bed upon which to set the steel and also protects the steel from rusting, as steel when completely buried in concrete will not rust. All structural steel should, however, be thoroughly cleaned and painted before it is set in place.

56. Spread Footings of Reinforced Concrete. Reinforced-concrete footings are those in which steel is used in combination with concrete to form the footing, as shown in Fig. 23. The steel furnishes the strength to resist the pulling apart of the concrete.

Spread footings constructed of reinforced concrete possess distinct advantages over steel-beam grillages. They can usually be erected somewhat more cheaply and they overcome the delay in waiting for structural-steel beams which is frequently encountered in building construction. In addition, they are not subject to corrosion, which might occur with steel-beam construction because of imperfect means of protection.

For buildings that are to be constructed entirely of reinforced concrete, spread footings of the same material are particularly desirable, because the reinforcing rods of columns and piers can be made to bond in the concrete of the footings.

57. Column Footings.—A usual type of spread footing of reinforced concrete is shown in Fig. 23, in which (*a*) is the plan, (*b*) a side elevation or view, and (*c*) a perspective view. The column is an **H** column. A metal base *a a* is riveted to the column and spreads the load from the column over the surface of the concrete so that the safe pressure on the concrete is not exceeded. The concrete footing *c* is likewise spread over a sufficient area of soil so that the safe bearing capacity of the soil is not exceeded.

The reinforcement consists of plain rods, square or round in section, or else of patented bars, twisted or corrugated, as shown in Fig. 27. The plain rods are apt to pull through the concrete under great stresses, whereas the twisted bars, shown in (*a*), and bars having projections, as in (*b*) and (*c*), will hold more securely in the concrete.

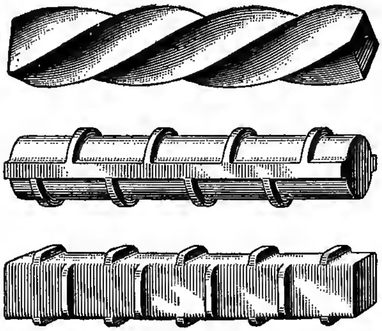


Fig. 27

The patented bars such as shown in the figure are more expensive than the plain bars but are much more efficient. A few patented or twisted bars will do the work of a greater number of plain bars.

The footing shown in Fig. 23 may be beveled off as shown at *a b* in (*b*) or it may be stepped off as shown at *c*. A saving in concrete is made by this treatment and the concrete omitted would contribute little or nothing to the strength of the footing.

When the column is set upon the concrete base, grout is poured in the holes *d* in (*a*), and fills all the voids between the bottom of the plate and the concrete footing.

58. Wall Footings.—Wall footings are used only under walls that are very limited in height. In buildings more than 40 or 50 feet in height, skeleton construction or reinforced-concrete construction is generally used. These types of construction concentrate the loads in columns and piers and the principal footings are therefore column footings.

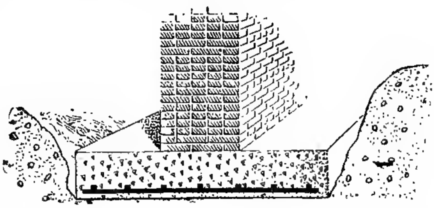
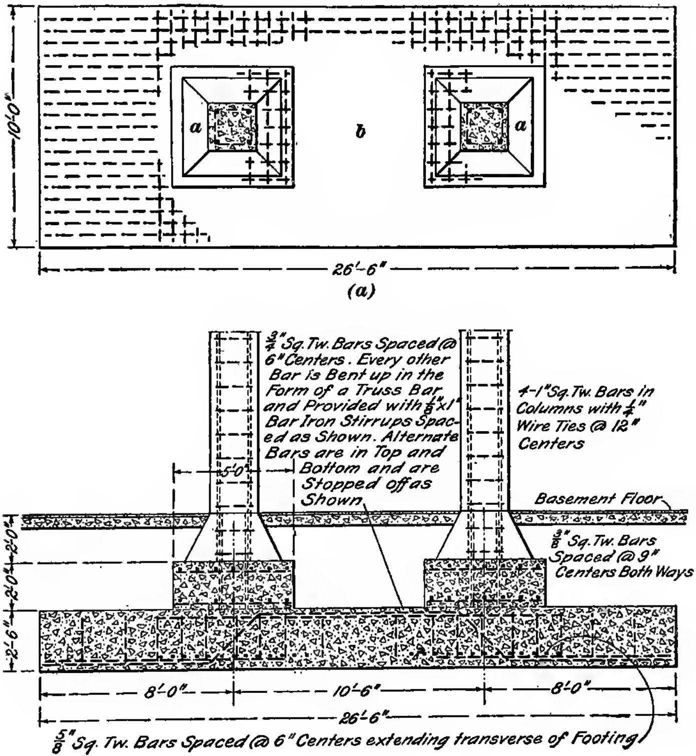


Fig. 28

For buildings of moderate height, reinforced-concrete footings are used. They are of a very simple type, as shown in Fig. 28, consisting of a slab of concrete reinforced with rods, and designed according to the principle used in designing cantilever beams.

COMBINED FOOTINGS

59. Connected Footings for Columns of Reinforced Concrete.—The conditions of construction sometimes make it advantageous to combine the footings under two adjacent columns, as shown in Fig. 29. This practice is advisable only where the area available for the footings is so limited as to prevent the use of separate spread footings. In (*a*) is shown a plan of the columns *a* that rest upon the common footing *b*; also some of the reinforcement is shown. In (*b*) is shown a section through the footing illustrating the arrangement of the reinforcing bars.


10'-0"
a
b
a
26'-6"
3/4" Sq. Tw. Bars Spaced @ 6" Centers. Every other Bar is Bent up in the Form of a Truss Bar and Provided with 1/8"x1" Bar Iron Stirrups Spaced as Shown. Alternate Bars are in Top and Bottom and are Stopped off as Shown
4-1" Sq. Tw. Bars in Columns with 1/4" Wire Ties @ 12" Centers
5'-0"
Basement Floor
3/8" Sq. Tw. Bars Spaced @ 9" Centers Both Ways
2'-0"
2'-0"
2'-6"
8'-0"
10'-6"
8'-0"
26'-6"
5/8" Sq. Tw. Bars Spaced @ 6" Centers extending transverse of Footing

(a)

(b)

FIG. 29

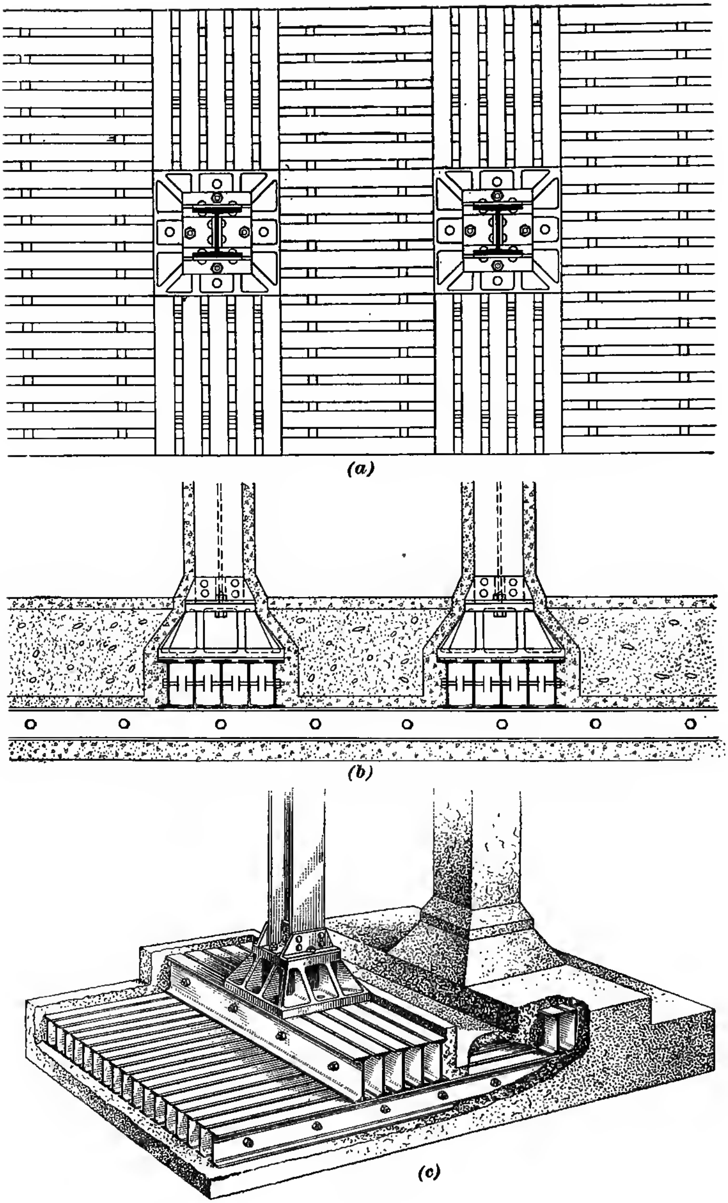


FIG. 30

The designing and detailing of such footings, or even of large-sized spread footings, are work for a specially trained engineer, to whom such work is usually referred by architects.

60. Footings of I beams are also made for supporting two columns, and this construction is illustrated in Fig. 30, which in (*a*) shows a plan; in (*b*) an elevation of such a footing, and in (*c*) a perspective view.

CANTILEVER FOOTINGS OR FOUNDATIONS

61. Where Cantilever Footings Are Used.—Most tall and heavy buildings are erected in large cities where the sites are very expensive and where the building cannot encroach upon adjacent property. The footings in such cases must be kept strictly within the boundaries of the lot. The footings of the wall columns are, in such cases, likely to be loaded eccentrically, that is, the load will be applied to one side of the footing. This has the tendency to press the footing down on one side as indicated in Fig. 31 (*a*), or else to break off the projecting part of the footing as indicated in (*b*).

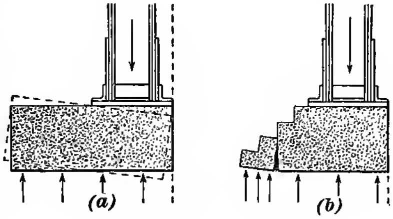


FIG. 31

62. The Principle of Cantilever Footings or Foundations.—In order to overcome the difficulty just mentioned, the cantilever foundations were designed. The principle of cantilever foundations is illustrated in Fig. 32, in which *a* represents the wall column, which is balanced or supported upon the end of a strong girder *b*, which acts as a lever. The bearing, or fulcrum, of this lever is the footing *c*, which is placed well within the property line *e f*. The weight of the column *a* is balanced by the weight of the column *d*, which is riveted to the other end of the girder *b*. In other words, the column *a* is supported on a large lever *b*, which is balanced on the footing *c*. By this arrangement the load acts on the center of the footing *c*, as indicated by the line *h g,* and produces an even pressure over the surface of the soil beneath the footing. The column *d* is designed to support a greater weight than the column *a* and has a grillage footing beneath it as shown.

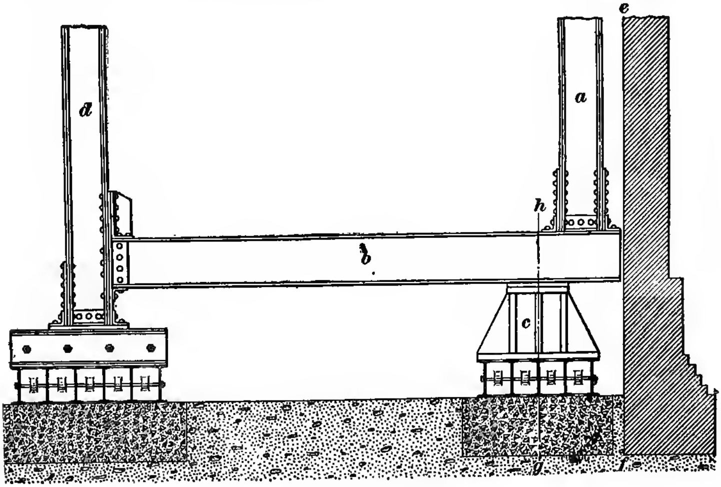


Fig. 32

DEEP FOUNDATIONS

63. Where conditions are such that the foundations cannot be spread over the ground by either stepped footings or spread footings it is necessary to resort to the use of deep foundations, which may be formed of piles or may be constructed by means of caissons. The subject of Piling is discussed in the Section on *Excavating, Shoring, and Piling.* The use and design of caissons are matters that are determined by engineers, and caissons are rarely if ever designed by architects. A brief description of caissons and their uses will, however, be given here to make plain the methods and possibilities of their use.

64. Caissons.—When it is necessary to penetrate a soft soil and reach rock foundations, caissons are used. A caisson is practically a box of large size, and may be square, round, or elliptical in horizontal section. It may be closed at the bottom or at the top and may be made of wood, steel, wood and steel, or of reinforced concrete. There are three types of caissons. One is the *open caisson,* which is open at the top and bottom. The sides are made water-tight, and the excavated material is taken out through the open top. The caisson sinks by its own weight but is sometimes forced down by weights that are placed on platforms constructed on top of it. The second type is the *box caisson,* which has a bottom but no top. This type is used mostly for bridge building and rarely for the foundations of buildings. When used for bridge building, a pier of masonry is started in the caisson and causes it to sink and rest on the bottom of the stream. The third type is the *pneumatic caisson,* which is open at the bottom and closed at the top; in it compressed air is used to keep out water so that workmen inside the caisson can remove the earth and rock beneath the caisson and thus allow it to sink as far as desired.

65. Pneumatic Caissons.—Pneumatic caissons are used when foundations must be carried down through soft soil to solid rock, as is necessary in case of heavy or high buildings. Though the sinking of caissons is expensive, it is an effective method and the foundations of adjacent buildings are less likely to be disturbed by it than by other methods.

Pneumatic caissons are made of timber, steel, reinforced concrete, or combinations of these materials. For footings of moderate size, steel caissons are used, while for larger foundations wood is employed.

66. The essential features of all pneumatic caissons are illustrated in Fig. 33. At *a* is shown the working space, or working chamber, which occupies the entire bottom of the caisson and is about 8 or 9 feet in height. In this chamber the workmen excavate the material *b* from beneath the caisson, which enables it to sink into the soil. The edge *c d* is called the *cutting edge* and is comparatively thin so that it will cut into the soil as the weight of the caisson bears upon it. The shaft, shown at *e,* is secured to the roof *f* of the working chamber. The men reach the working chamber through this shaft, and the soil excavated in the working chamber is hoisted through the shaft in the bucket *g*. In the working chamber and the shaft an air pressure must be maintained sufficient to prevent water from the surrounding soil from entering beneath the caisson. To accomplish this, the shaft is closed at the top by an air lock *h*, and the air pressure is furnished by an air compressor on the surface through pipes such as *i*.

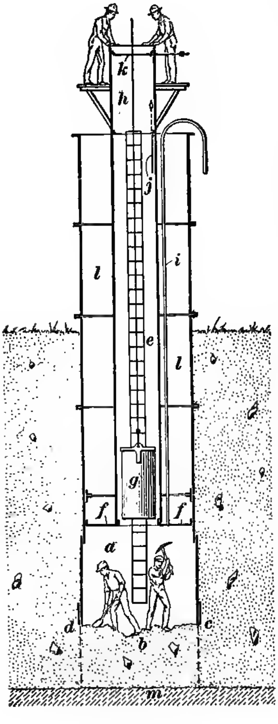


Fig. 33

The air lock allows entrance to and exit from the shaft without the loss of air pressure and also furnishes the means for a gradual change of pressure upon persons going in or out. This gradual change is necessary, as serious injury results to persons coming too quickly from high pressure to the ordinary pressure of the atmosphere. The air pressure in the working chamber is sufficient to keep the door *j* closed. To allow a man to enter the caisson, the door *k* is opened and the pressure of air in the lock *h* is the same as that of the outer air. The man enters *h*, and the door *k* is closed, and compressed air is introduced into the air lock. When the pressures in the air lock and in the working chamber are equal, the door *j* is opened and the man can descend by means of a ladder which is built inside the shaft. For a man going out, the operation is reversed, the door *j* being closed and the pressure in *h* being allowed to fall very gradually until atmospheric pressure is reached, when the door *k* can be opened.

In sending up a bucket filled with soil the door *k* is closed and the air lock filled with compressed air until the pressures in *h* and *e* are equal, when the door *j* is opened, the bucket is drawn up into *h*, and the door *j* is closed. The pressure in *h* is then reduced until it is the same as that of the outer air, when the door *k* is opened and the bucket hoisted out into the open air.

67. A crib, or cofferdam, *l l* is secured to the top of the working chamber and may be made of steel or wood. It is of the same size horizontally as the working chamber and sinks with it. It is virtually a form for the concrete pier that is afterwards formed in the caisson.

When the caisson has been sunk to the rock surface *m* the working chamber is filled with concrete, after which there is no danger that water will enter the caisson. The air pressure is then no longer necessary. The shaft and the air chamber are then removed and the roof of the working chamber is left in place. The entire caisson is then filled with concrete and a solid pier is formed upon which the columns of a building can rest.

FOUNDATION WALLS

MATERIALS

68. Foundation walls may be built of stone, concrete, brick, or hollow terra cotta. The choice will depend upon the cost, and upon the ease with which the material can be obtained.

Stone is one of the best foundation materials and in localities where it is abundant and easily quarried it is a cheap and desirable one. Where sand and gravel are plentiful, concrete is an excellent and cheap article to use. In some localities stone, sand, and gravel are not easily obtained, and brick and terra-cotta blocks are found to be the most advantageous materials to use.

FOUNDATION WALLS OF VARIOUS MATERIALS

69. Stone Foundation Walls.—Stone foundation walls below ground, when concealed from outside view, are usually constructed of rough rubble, as shown in Fig. 34. This represents an elevation (*a*) and section (*b*) of a 20-inch rubble stone wall, shown at *a, a,* 8 feet high, with footing stones *b,* 8 inches thick and 2 feet 8 inches wide. At *c* is shown a drain used to keep the drainage water from the surface of the wall.

Stone foundation walls should be bonded together, as shown in Fig. 35, where *a* shows the bond stone, or header. All stone walls 24 inches or less in thickness should have at least one header extending through the wall every 3 feet of height and every 4 feet of length. If the stone wall is over 24 inches thick, there should be at least one header for every 6 superficial feet of wall space, running into the wall at least 2 feet. The headers should not be less than 18 inches in width and 8 inches in thickness, and should be good flat stones. These headers serve to bind the stones together in the walls, and keep the foundation from splitting apart crosswise when weight is placed on it.

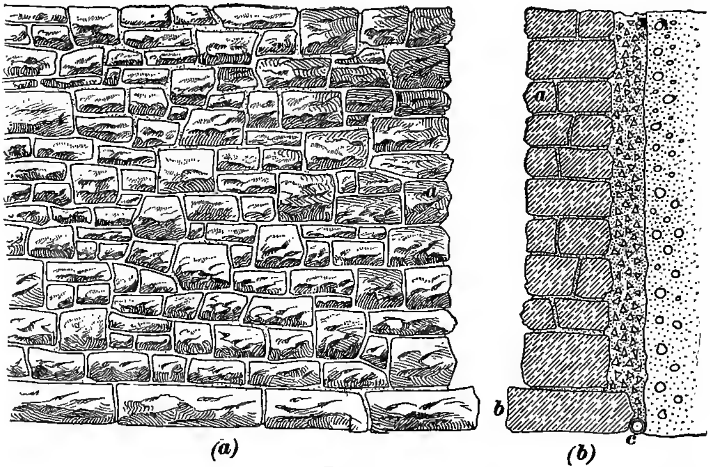


Fig. 34

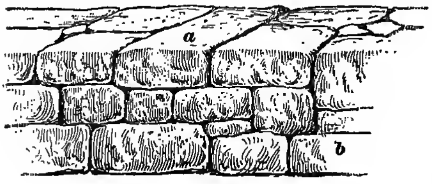


Fig. 35

70. All wall angles should be well tied by long stones laid alternately in the wall, as shown at *a*, Fig. 36, the long angle stones tying the wall at that point. By using these long stones, the weight on the corners of the wall is more equally distributed, and the wall can be kept plumb and true.

71. Foundation stones should always be laid on their natural, or quarry, beds. The tendency to splitting, or cleavage, in a stone is with the grain or bed; so when the stone is laid on its original bed, the weight of the material placed above it comes against the grain of the stone. No stone should have more face than bed, and one side, at least, of each stone should be flat. Every stone should be well bedded in mortar.

72. The usual practice among masons in rough walling is, after setting the larger stones, to fill the interstices with spalls or chips of stone, or even pebbles, more or less carefully fitted, and put in dry; then to dash in mortar, trusting that it will work its way into the crevices. It does so to some extent, but the method is not a good one. A good, conscientious workman will place no stone, even the smallest chip, except in a bed of mortar prepared to receive it, rubbing it well in, and settling it with blows of the trowel and hammer, so that all the stones have a layer of mortar between them.

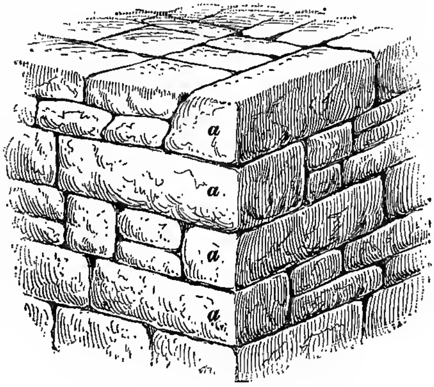


Fig. 36

A common practice is to grout the walls with mortar made so thin that it will flow into the spaces between the stones.

73. For good work, it is necessary that the outside of the wall (even when concealed by the excavated bank) should be carried up with a good face, and the joints well filled with either cement, or lime-and-cement, mortar. If this is properly done, any moisture that runs out from the bank or descends from above, so as to flow down over the outer face of the wall, will drip off, instead of running into the joints.

The space between the outside of the foundation and the bank of the excavation should be filled with gravel or sand (preferably the former), well packed down. Water will then soak through this sand or gravel to the drain below; this method makes the cellar drier and warmer, and keeps much of the moisture away from the foundation walls.

74. Brick Foundation Walls.—Brick is commonly used for foundation walls. It has, however, one disadvantage in being somewhat porous. When it is used for foundation walls in damp or wet soils it absorbs water and becomes wet, which causes dampness in the cellar of the building. In dry sandy soils this cannot happen and brick is an excellent material to use.

75. Concrete Foundation Walls.—Concrete is an excellent material to use for building foundation walls and is being used more and more for this purpose. There is little choice between a good stone wall and a concrete wall. The cost and convenience of building are the considerations that regulate the choice of one or the other.

76. Concrete Blocks for Foundation Walls.—Concrete blocks are frequently used for foundation walls for small buildings. They have the advantages of concrete, but do not require the use of forms in erecting the wall. The building codes of some cities require that when these blocks are used for foundation walls the hollow spaces in the blocks shall be filled in solid with concrete. This makes each block, in effect, a solid block of concrete and produces a wall which is similiar to a stone wall.

77. Terra-Cotta Hollow-Tile Foundations.—In some portions of the United States, hollow terra-cotta tiles are used for foundation walls. They are used for small buildings that are light in weight. The Chicago laws allow the use of terra-cotta tiles in buildings not exceeding four stories in height. The building code of New York City requires that the hollow spaces in the tile shall be filled solid with concrete when used for foundation walls. The cities of Pittsburgh and Philadelphia do not permit the use of hollow terra-cotta tile in foundation walls.

In using terra-cotta tile in foundations it is good practice to have the material vitrified, as the unvitrified terra cotta is apt to be affected by contact with certain kinds of soils, unless it is burned so that it is very hard. Vitrified conduits, such as are used for underground telephone and telegraph conduits, are excellent for building foundation walls. They are made in various sizes and are readily obtainable. As they are 30 inches in length they can be laid quickly and are therefore economical to use.

THICKNESS OF WALLS

78. Thickness of Foundation Walls.—The thickness of a rubble stone wall should never be made less than 18 inches, which may be allowable when the stones are stratified and have the upper and lower beds about parallel, and never less than 20 inches when the stones are very irregular in shape without flat beds.

The best practice regarding foundation walls is that prescribed by the building codes of most cities. Most of these codes require that the foundation walls of stone shall be at least 8 inches, and of brick 4 inches, thicker than the masonry wall which rests upon them. The thickness of stone walls shall never be less than 20 inches and of brick walls 12 inches. If the wall extends more than 12 feet below the curb it must be made 4 inches thicker for every additional 10 feet below the curb.

Thus, if the first-story walls which rest directly upon the foundation walls are 12 inches in thickness, the foundation walls, if of stone, must be 20 inches in thickness; if of brick, 16 inches in thickness. If more than 12 feet below the curb, they must be 24 inches and 20 inches, respectively.

A stone wall 18 or 20 inches thick may not always be necessary to carry the load that it supports, but smaller walls are more difficult and expensive to build and consequently are seldom constructed.

The required thickness of walls in general is almost impossible to determine except by experience. The results of such experience are incorporated in the building codes referred to.

79. The thickness of concrete walls, as well as of terra-cotta hollow tile and hollow concrete blocks, is generally required to be the same as for brickwork walls.

80. Cellar walls are often subjected to a side pressure, or pressure perpendicular to the height of the wall, due to masses of earth pressing against them. In such cases they should be made thicker in accordance with the principles stated in the Section on *Areas, Vaults, and Retaining Walls.*

MORTAR

81. Mortar.—While lime mortar is frequently used in building foundation walls, Portland-cement mortar is considered the best to use. It is required by some of the building codes that cement mortar alone shall be used in all work that is done below the surface of the ground.

OPENINGS IN WALLS

82. Openings for Pipes.—As drainage, sewer, water, and gas pipes generally go through the foundation walls of buildings, provision should be made that they shall be protected from breakage or crushing, in case of a settlement in the walls. It is always better to leave openings for such pipes when building the walls, as it is sometimes a difficult and expensive matter to cut holes through the wall after it has been built. This is particularly true of stone and concrete walls.

Openings for large pipes, such as house drains, should be covered over with stone lintels in stone and brick walls. In concrete walls, wooden boxes should be set in the forms so as to retain an opening at the required point. These openings should be made somewhat larger than actually required for the pipe and the top of the opening should be kept 2 or 3 inches above the top of the pipe so that if the wall should settle it will not bear on the pipe. For smaller pipes, short sections of larger pipes may be set in the wall through which the small pipes may pass.

In cases where water is likely to come in through these openings and around the pipe, this space should be filled with a soft composition such as asphalt or tar mixed with sand or with paraffin. If a settlement should occur, these compositions will yield and the pipe will not be injured; at the same time the water will be kept out.

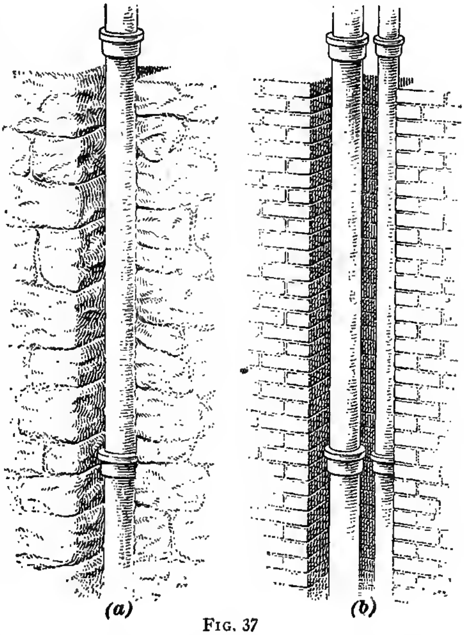


Fig. 37

83. Chases.—Chases are vertical channels left or cut in the wall to receive plumbing, heating, or other pipes, as shown in Fig. 37, where in (*a*) is shown a chase in a stone wall and (*b*) a chase in a brick wall.

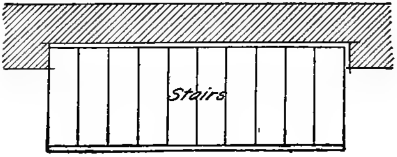


Fig. 38

In Fig. 38 is shown a recess, or chase, in the foundation wall to accommodate a flight of stairs to the cellar, and in Fig. 39 a chase for a dumb waiter. These chases are best built in the walls, as it is very expensive to cut them out of the completed wall.

84. Openings for Windows.—Where there are doors or window openings in a foundation wall there will be considerable pressure on each side of the opening, whereas there will be none under it. By arranging the stones under the opening in steps as shown in Fig. 40, at *a*, *b*, and *c*, this pressure will be spread evenly throughout the wall under the opening.

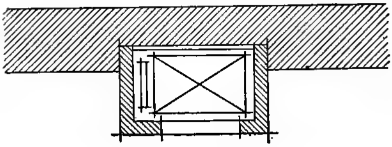


Fig. 39

When the weight on the walls is great, the window sills are frequently made just the length of the opening, as shown at *d*, so as not to project into the wall at each end in the usual manner. This avoids the pressure on the sill which would tend to break it. This style of sill is known as a *slip sill.*

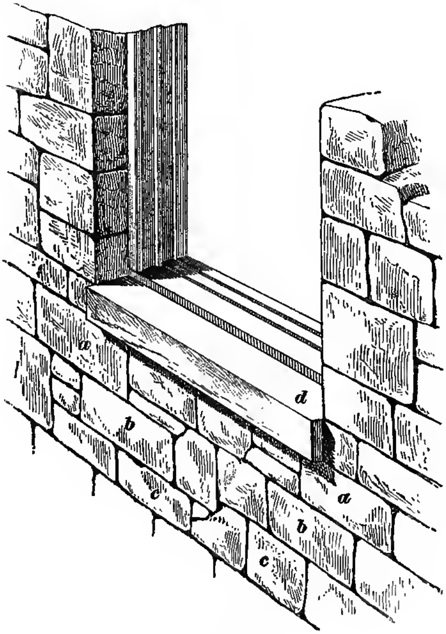


Fig. 40

FOOTINGS AT DIFFERENT DEPTHS

85. To Avoid Disturbance of Footings.—In building it frequently happens that, in columns adjacent to each other, the footings are at different levels, as shown in Fig. 41. Such a condition would occur, for instance, when the floor of a boiler room is at a lower level than the basement floor. In digging the pit to receive the footing of the column *a* the soil under the column *b* is likely to be undermined. The soil would probably remain in place on a line *x x* and distribute the load from the column to the soil beneath. If, however, the soil is excavated inside the line *x x*, as at *c*, the foundation bed under the column *b* will be disturbed and its support will be diminished. It is wiser in such cases to carry the foundations under *b* down solid to the level of those under *a*, as indicated by the dotted lines at *d*.

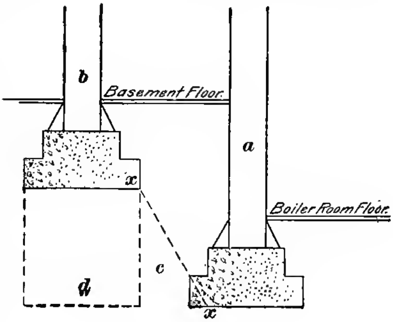


Fig. 41

86. Foundation Walls Partly on Rock.—A very faulty construction sometimes met with is that in which a portion of a ledge of rock projects into the foundation wall, and the foundation is built partly on the rock and partly on the footing course. This is shown in Fig. 42, *a* being the footing course; *b*, the rock projection into the foundation

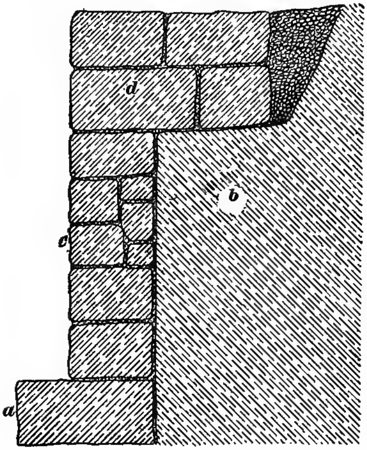


Fig. 42

wall; *c*, the thin wall in front of the rock to bring the foundation to the thickness required in the plans; and *d*, the foundation wall carried up to its full height and thickness, and resting partly on the thin wall *c* and partly on the ledge of rock *b*.

In a wall so built, the water will find its way either through the imperceptible seams of the ledge of rock *b*, or over its top into the body of the masonry, keeping it constantly damp. Besides, there is a serious risk that under the heavy weight of the upper wall, the thin lining built up against the ledge—but in no way bonded to it—will separate from it and fall away, leaving the superincumbent masonry most insecurely supported upon the rock alone. There is, besides, the certainty that the foundation wall, built partly on unyielding rock and partly on softer soil, will settle unequally, and crack, perhaps injuring the masonry above beyond repair, and, at least, opening an inlet for moisture.

The ledge should be cut away so as to leave ample space for the whole thickness of the foundation walls down to the footings, with sufficient space between the wall and the ledge of rock for packing gravel. This will intercept the water and carry it away from the wall.

WATERPROOFING

CONDITIONS THAT REQUIRE WATERPROOFING

87. General.—Damp cellar walls are due either to water soaking through from the outside or to wet soil underneath the foundations, from which water rises in the walls by **capillary attraction,** that is, the water is soaked up by the stone or brick as it would be by a sponge. The capacity for absorbing water depends upon the nature of the material used in building the wall and is more noticeable in brick than in stone or concrete.

Some clay soils, though sufficiently solid to support the walls of dwelling houses, still, in wet seasons, retain moisture that is not carried away into the earth but rises in the cellar and keeps it almost always damp.

Sandy or gravelly soils readily absorb moisture and generally carry it away rapidly, so that a cellar built in such soils is rarely damp.

In some places, particularly where near a lake or river, the water stands at a fixed level in the soils, and cellars carried below this level are pretty sure to be wet, unless they are thoroughly waterproofed. In such localities the water tends to rise in the cellar until it has reached the level of the water standing in the surrounding soil, thus producing an upward pressure beneath the cellar floor. This pressure is called *hydrostatic pressure,* and when the cellar is waterproofed this upward pressure must be opposed by making the cellar floor of a sufficiently heavy construction.

88. When excavating for the cellar, if a depth is reached where water comes into the excavation and tends to remain at a certain level, it will be absolutely necessary to waterproof the cellar or it will always be wet.

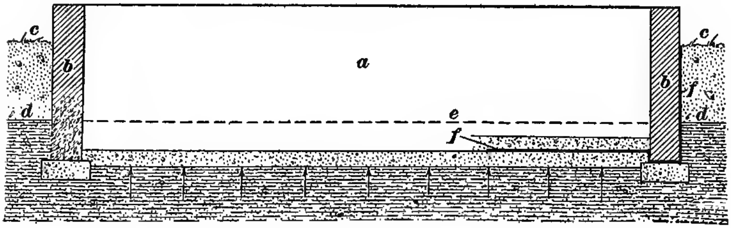


FIG. 43

89. Fig. 43 illustrates conditions that call for waterproofing in a cellar. A cellar is shown in vertical section at *a,* the cellar walls at *b,* the grade or natural surface of the ground at *c c,* and the level at which water is likely to stand in the ground at *d d.*

If this cellar is not waterproofed, the water will tend to fill the cellar up to the level *e,* and also water will soak up into the cellar walls, even above the line *e,* according to their porosity. If the cellar walls and all the floor are waterproofed in the manner indicated in part by the heavy line *f f,* the tendency of the water to rise to the level *e* will produce an upward pressure, or hydrostatic pressure, under the cellar floor as indicated by the arrows and will tend to push up the floor, or at least the floor above the waterproofing, and the floor will have to be made of sufficient thickness to neutralize this upward pressure by its actual weight.

90. The presence of water in the foundation walls is likely to be injurious to the walls, as there are sometimes soluble elements in the wall material that are washed out. The walls are also subject to the action of frost, which expands and contracts the water in them and thus tends to disintegrate them. A damp cellar is also frequently a menace to the health of the occupants of the house.

91. Methods of Waterproofing.—There are three methods that are used for damp-proofing and waterproofing foundation walls and cellars. The first method consists of applying a coating of impervious material such as cement, asphalt, coal-tar pitch, or certain patented coatings.

The second method is called the **membrane method** and consists of applying a covering to all parts of the structure that are in contact with water. This covering consists of several layers or thicknesses of burlap or paper which are pasted together and to the wall or floor with hot asphalt or coal-tar pitch. The idea of using the burlap or paper is to form a tough coating that will not be broken in case there is a slight settlement of the building.

The third method, which is known as the **integral method,** consists of building the foundations and cellar floors of concrete with which has been mixed a patented preparation which is intended to make the walls and floors impervious to water.

Drainage is often employed in drawing the water away from the walls and from beneath the floors of cellars. This avoids the necessity of expensive waterproofing. Drainage is often used in connection with waterproofing, as will be shown later.

EXAMPLES OF VARIOUS METHODS

92. Coating.—If only surface water is to be guarded against, cement, asphalt, or coal-tar pitch applied to the outside of the cellar wall is usually sufficient to insure a dry cellar. It is often specified that foundations shall be covered on the outside with a coating of mortar composed of 1 part Portland cement and 1 part sand troweled on about 1 inch in thickness.

Hot asphalt or coal-tar pitch applied to the outside of a wall is considered sufficient to protect the wall where only surface water is to be considered. When these coatings are used the walls must be carefully built and the joints well pointed. The wall must also be thoroughly dry before such coatings are applied.

A coating of asphalt or coal-tar pitch is sometimes applied over a coating of cement. Such coatings are generally stopped just below the surface of the ground so that they will not affect the appearance of the wall above the grade.

93. Fig. 44 shows a section through a cellar wall of a dwelling. The wall *a* is coated with cement *b*, which is in turn coated with coal-tar pitch *c*. There is also shown a drain *d* at the bottom of the space between the wall and the embankment. This space is filled with broken stone, gravel, or sand and the water falling near the wall passes through these materials easily and into the drain of porous pipe with uncemented joints, which leads to a cesspool.

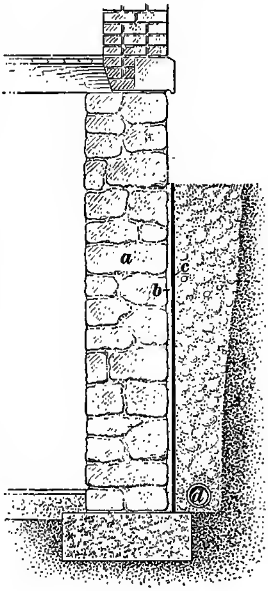


FIG. 44

94. The Membrane Method.—Where there is considerable water in the ground at all times, or even during certain seasons of the year, and where there is likely to be hydrostatic pressure, the membrane method is used.

The membrane is made of from three to six layers of felt or heavy paper. The first layer of paper is pasted on the wall with coal-tar pitch and the succeeding layers of felt are pasted to the previous ones by the same material. The final coating is also of pitch.

An example of a wall and cellar that is waterproofed by the membrane method is shown in Fig. 45, in which *a* is the wall, *b* the footing, and *c* the cellar floor.

Sometimes there is not sufficient space on the outside of a wall to allow the men to work in putting on a coating such as this, in which case it is customary to build a wall of brick or terra-cotta blocks from 4 inches to 8 inches in thickness, as at *d*, and stick the membrane *e* to it; the wall *a* is then built against the waterproofing as shown.

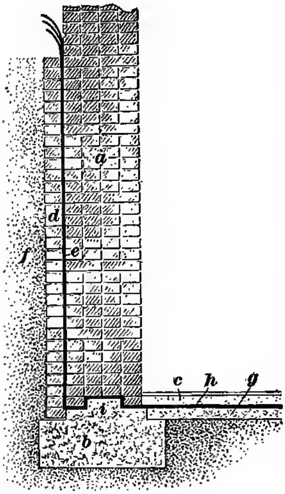


FIG. 45

On the top of the footings *b* a break *i* is formed which helps to prevent water from penetrating the wall at this joint and forms a bond with the wall above. The waterproof menbrane is applied to the wall *d*, is carried over the lower part of the wall and the break *i*, and is allowed to project about 8 or 10 inches into the cellar so as to form a connection with the cellar waterproofing. The wall *a* is then completed, being built against the wall *d*. The earth filling *f* holds the wall *d* tightly against the wall *a*, and between these walls the membrane is protected from injury.

When the cellar floor is laid, a layer of concrete *g* is first placed directly on the soil and leveled off to receive the membrane *h*. This membrane is formed of several layers of felt between layers of pitch and is carefully joined to the membrane that projected through the wall so as to make a continuous water-tight seal as shown by the black line. A layer of cement mortar is then placed on top of the membrane and serves as a protection for the membrane as well as for a floor. If the hydrostatic pressure is great, the layers of concrete which make up the floor must be made heavy enough to counteract the upward pressure of the water.

95. The Integral Method.—The integral method of waterproofing consists of making walls waterproof throughout. This can only be done in the case of concrete walls. A patent preparation, either a powder, a paste, or a liquid, is mixed with the ingredients of the concrete and when this mass sets it is impervious to moisture. If a powder is used it is thoroughly mixed with the dry cement; if a paste or liquid preparation is used it is mixed with the water which is used in mixing the concrete. It is essential that the waterproofing shall be thoroughly mixed in the concrete so that all parts shall be equally impervious.

In placing this concrete it should be put in position, as far as possible, in one continuous operation, as joints in the concrete are hard to make so that they will not leak.

An example of a floor and cellar wall built according to the integral method is shown in Fig. 46. A wall is shown in section at *a*. This wall is waterproof in itself and consequently needs no coatings. The same is true of the floor *b*. A wearing surface *c* of cement and sand is placed on top of the waterproofed concrete *b*.

In Fig. 47 is an example of a coating of integral waterproofing applied to the inside of the cellar wall and also as a finishing coating to the cellar floor. This coating does not prevent water from entering the wall itself but prevents it entering the cellar. This method is followed when it is impossible to reach the outside of the wall to apply a coating. When it is necessary to keep the water out of the wall and the outside of the wall can be reached, a coating of integral waterproofing cement can be applied over the outside of the wall as shown in Fig. 48. A layer of the waterproof cement must be placed on the footing beneath the wall so as to connect with the cement on the outside of the wall and with the floor inside the wall.

96. Drainage.—Where there is water that has a tendency to enter a cellar, it may be possible to remove it by means of drains, thus doing away with the necessity for extensive waterproofing. Drains for this purpose are made of porous terra-cotta pipe laid in a trench all around the outside of the foundation walls, as indicated in Fig. 44 at *d*. The joints of the pipe are uncemented, and over the upper side of each is laid a piece of tarred paper or a small segment of pipe to keep out any solid matter, but to allow water to leak into the joint. The trench is filled with broken stone, gravel, or sand, so that the water will sink readily to the bottom, where it passes through the pores and joints into the pipe and is carried to a sewer or cesspool. Similar drains may also be laid under a cellar floor if conditions require.

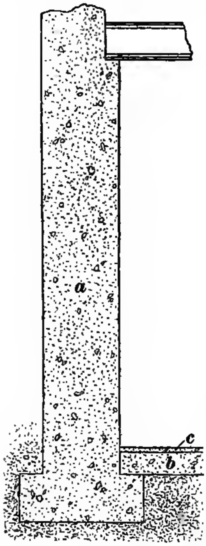


Fig. 46

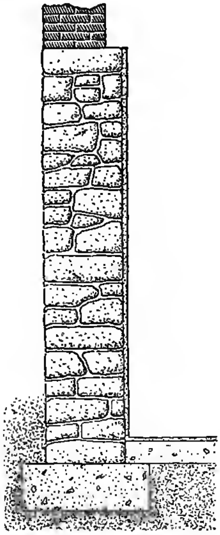


Fig. 47

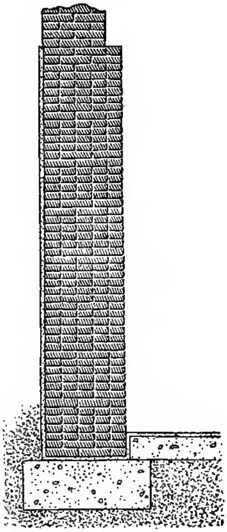


Fig. 48

STONE MASONRY

TERMS USED IN STONE MASONRY

1. Parts of a Stone.—The names given to the parts of a block of stone when prepared for a structure are here defined. The **face** is the surface that will be exposed to view. The **back** is opposite the face, and parallel, or nearly so, to it. The upper and the lower horizontal surfaces (as laid) are called **beds,** and are distinguished, respectively, as the *top bed* and the *bottom bed.* The height, or distance between the top and bottom beds, is called the **rise** or **build.** The vertical sides at right angles to the face are called the **joints.** The four edges of the face, when they have been sharply defined by the use of the chisel, are termed **pitch lines** or **arrises.**

A stone used at the corner of a wall and showing two faces is called a **quoin.** Small pieces of irregular-shaped stone are called **spalls.** A cut stone is said to be *spalled* when a portion of the edge has been broken off.

When the blocks of stone are so large as to require machinery to move them, a hole, of the shape of an inverted truncated wedge, is cut in the center of the top bed to receive a device called a **lewis,** Fig. 1, to which the hoisting rope from the derrick is attached. Otherwise, two holes are cut obliquely in the top bed to receive bolts with eyes for the same purpose. When the device called a **dog,** or **grab,** is used, small holes are drilled in the sides of the stone, to receive its points. The holes should be so placed as not to mar the appearance or affect the durability or strength of the stone, and should never be placed in the faces of fine cut stones. The holes are variously designated as *lewis holes, grab holes, dog holes,* etc.

COPYRIGHTED BY INTERNATIONAL TEXTBOOK COMPANY. ALL RIGHTS RESERVED

2. Parts of a Wall.—The **footings** of a wall are the projecting courses at the base of the wall, employed for the purpose of distributing the weight over an increased area of soil and thereby diminishing the liability to vertical settlement from compression of the ground.

The **face** is the portion of the wall exposed to view, and the **back** is the inner portion.

3. Each horizontal row or layer of stone is called a **course.** Some of the courses have particular names. The **plinth,** also called the **water-table,** is a projecting course placed at or near the ground line. The **belt-courses** or **string-courses** are horizontal courses placed at intervals on the face of a building for the purpose of ornament. The course from which an arch springs is called the **springing course.** A **stretching course,** or **stretcher course,** is a course composed entirely of stretchers. A **header course** is a course composed of headers. A **bonding course** is a course composed of bond stones. The terms *stretcher, header,* and *bond* are defined further on. The **corbel course** is composed of pieces of stone projecting from the face of the wall, for the purpose of supporting a course that projects still farther. The **cornice** is the ornamental course or courses generally set at or near the top of the wall.

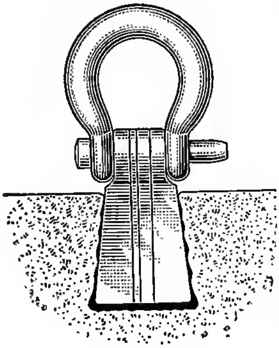


FIG. 1

4. The **coping** is the finishing course at the top of the wall, and consists of large stones projecting slightly over the wall at both sides, accurately bedded on the wall and joined to one another with cement mortar. The coping is used to shelter the mortar in the interior of the wall from the weather, and to protect, by its weight, the smaller stones below it from being knocked off or picked out. Coping stones should be so shaped that water may rapidly run off them. For coping, long stones are preferable to short ones, because the number of top joints will be diminished and the mass beneath the coping will be better protected. Additional stability is given to a coping by so connecting the stones that it will be impossible to lift one of them without at the same time lifting the ends of the two stones next to it. This is done either by means of metal **clamps,** or **cramps,** which have the ends turned at right angles to the body of the bar, and are inserted in holes cut in the stones and fixed there with lead, or by means of **dowels** of wrought iron, cast iron, copper, or hard stone. The metal dowels are inferior in durability to those of hard stone, although they are superior in strength. They are fastened by pouring melted lead or sulphur around them. Copper is strong and durable, but expensive. The stone dowels are small prismatic or cylindrical blocks, each of which fits into a pair of opposite holes in the contiguous ends of a pair of coping stones and is fixed with cement mortar.

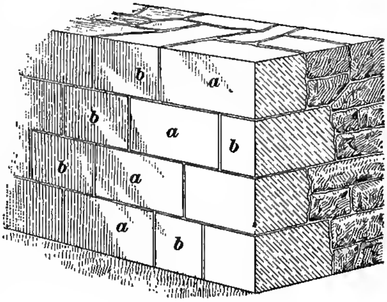


FIG. 2.

The under edge of the coping should be provided with a **drip;** that is, grooved so that the water falling on it will not run back on the wall, but will drop from the edge.

5. The term **bond** is applied to the method adopted for placing the stones or bricks in a wall, by lapping them over one another, so as to prevent the vertical joints from forming a continuous straight line, the occurrence of which would produce a weak and easily separable structure. A good bond breaks the vertical joints, both in the length and in the thickness of the wall.

Various methods are employed to form the bond. The method by **headers and stretchers,** in which the vertical joints of each course alternate with the vertical joints of the courses above and below it, is the simplest and the most commonly used. In this method, shown in Fig. 2, the blocks of each course are laid alternately with their greatest and least dimensions to the face of the wall. Those that present the longest dimension, as *a*, are termed **stretchers;** the others, as *b*, are termed **headers.** This arrangement of headers and stretchers is termed the **longitudinal bond.** Its object is to distribute the load or pressure over an increasing area downwards to the foundation. The extent to which the blocks should overlap or break joint is usually from one to one and one-half times the rise, or height, of the course.

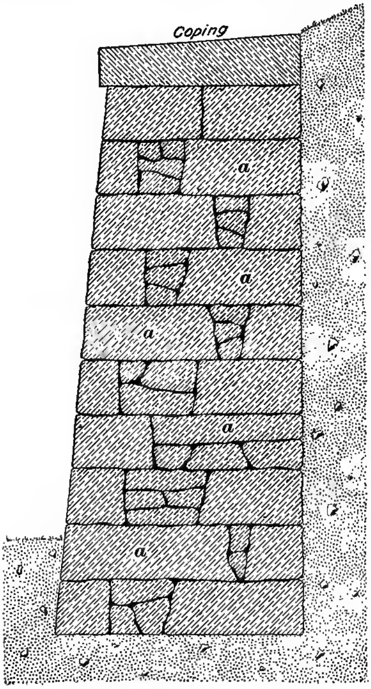


FIG. 3

The bond across the thickness of the wall is of more importance than the longitudinal bond; its object is to tie the face and the back of the wall together; this is effected by the headers. A header that extends from face to back is termed a **through bond.** When walls exceed 3 feet in thickness, it is not advisable to use through bonds, because of the liability of the long stone to become broken in the middle by unequal settlement; in its place headers that reach only a part of the distance are used. In this case, they are called **binders** and should extend from each face about two-thirds of the thickness of the wall, as shown at *a*, Fig. 3; they should be arranged so as to cross each other alternately. The strongest bond in masonry composed of rectangular stones is that in which each course at the face of the wall contains a header and a stretcher alternately, the outer end of each header resting on the middle of a stretcher in the course below; so that rather more than one-third of the area of the face consists of ends of headers. This proportion may be deviated from when circumstances require it; but in every case it is advisable that the ends of headers should form not less than one-fourth or one-fifth of the whole area of the face of the wall.

6. Joints.—The mortar layers between the stones are called the **joints.** The horizontal joints are called **bed joints,** or simply **beds.** The end joints are called **vertical joints.** When the term *joint* is used without any qualification, a vertical joint is meant. Excessively thick joints should be avoided. For ashlar masonry, joints should be about $\frac{3}{16}$ to $\frac{1}{2}$ inch thick; for rubble masonry, they vary according to the character of the work.

Joints of masonry are finished in different ways, with the object of presenting a neat appearance and of preventing water from entering the wall. The joints most used in ashlar masonry are: (1) **Flush joints,** Fig. 4, in which the mortar is pressed flat with the trowel, and the surface of the joint is flush with the face of the wall. (2) **Struck joints,** Fig. 5, formed by pressing or striking back with the trowel the upper portion of the joint, while the mortar is moist, so as to form an outer sloping surface from the bottom of the upper course to the top of the lower course. This joint is also called a **weathered joint.** Masons generally form this joint so that it slopes inwards, thus leaving the upper arris of the lower course bare and exposed to the action of the weather. The reason for forming the joint in this manner is that the work is more easily done. (3) **Keyed joints,** or **tooled joints,** Fig. 6, formed by drawing a curved iron key or jointer along the center of the flushed joint and pressing it hard so that the mortar is driven in beyond the face of the wall. A groove of

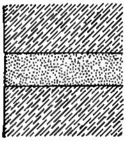


FIG. 4

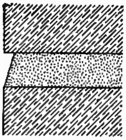


FIG. 5

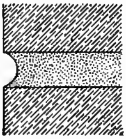


FIG. 6

curved section is thus formed, having its surface hardened by the pressure.

7. Among other forms of joints that are used is the *raised, ruled,* or *rodded joint,* the purpose of which is to give a uniformity of effect in the joints that is not natural to rubble. Rubble treated with raised joints looks as if all the stones had straight edges and evenly cut joints, whereas, the effect is due entirely to the treatment of the mortar joints. Fig. 7 (*a*) shows a sample of this kind of jointing. The irregular stones *a* are built into the wall, and when the wall is finished they are pointed up as nearly flush as possible, as shown at *b*, and the raised joint is formed as shown at *c*. In order to make these joints, a sufficient quantity of mortar is placed along the joint and pressed down to an even surface. By the use of a straightedge of wood and a small trowel, these raised joints are cut straight on each edge, forming a straight rectangular projection as at *c*. The stones should be hammer-dressed to make the edge of the stone approximately straight so that the joints will not be too wide. The general effect of this kind of pointing is illustrated in Fig. 8.

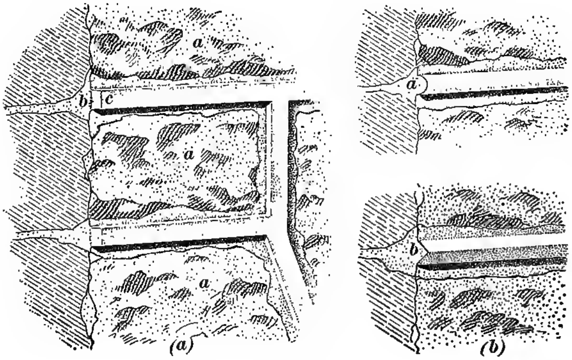


FIG. 7

Another form of a raised joint is illustrated in Fig. 7 (*b*), where the raised portion of the joint is curved or **beaded,** as shown at *a*, or **V**-*shaped,* as at *b*. A joint such as this is formed by a tool with a hollow half-round or a **V**-shaped edge.

8. Pointing a piece of masonry consists in scraping out the mortar in which the stone was laid, from the face of the joints for a depth of from ½ inch to 1 inch, and filling the groove so made with fresh Portland-cement mortar, made of one part of cement and one part of sand. The necessity for pointing arises from the fact that the exposed edges of the joints are always deficient in density and hardness, and the mortar near the surface of the joint is specially subject to dislodgment, since the contraction and expansion of the masonry are likely either to separate the stone from the mortar or to crack the mortar in the joint, thus permitting the entrance of rainwater, which by freezing forces the mortar from the joints.

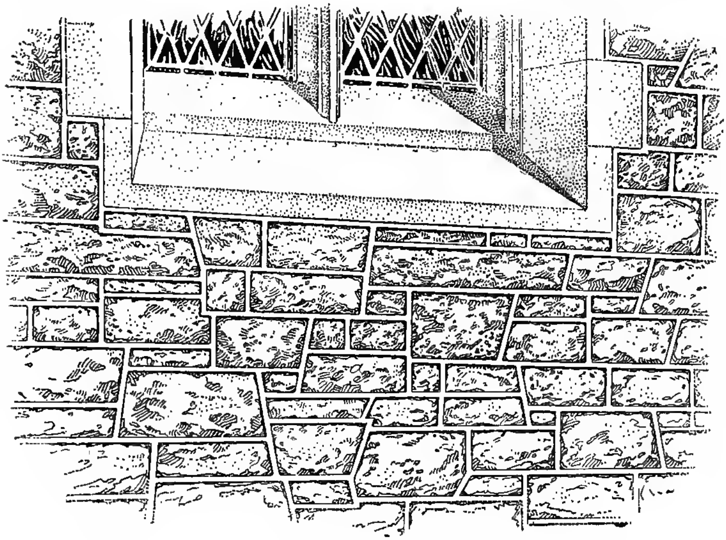


Fig. 8

The pointing mortar should be mixed with just enough water to hold it together. Before applying the mortar, the joint must be well cleaned by scraping and brushing out the loose mortar, then thoroughly saturated with water and maintained in such a condition of dampness that the stones will neither absorb water from the mortar nor impart any to it. Walls should not be allowed to dry too rapidly after pointing. Pointing should not be done either during freezing or during excessively hot weather. The pointing mortar is applied with a mason's trowel, and well pressed into the joints. In the very best work, the surface of the mortar is rubbed smooth with a jointer. The form given to the finished joint may be any of those described in Art. **6.** Pointing with colored mortar is frequently employed to improve the appearance of the work. Various colors are used, as white, black, red, brown, etc., different-colored pigments being added to the mortar to produce the required color. Many authorities consider that pointing is not advisable for new work, as the joints so formed are not so enduring as those finished at the time the masonry is built. Pointing is, moreover, often resorted to when it is intended to give the work a superior appearance and also to conceal defects in inferior work.

CLASSES OF MASONRY

RUBBLE MASONRY

9. The stonework entering into the construction of buildings may be divided into three classes: *rubble, ashlar,* and *trimmings.* Of these, rubble will be described first.

Rubble, or **rubblework,** is stonework that is built of rough irregular-shaped stones as they come from the quarry, these stones being roughly trimmed, when necessary, to fit against each other in the wall. This work is done by means of a mason's hammer. The stones should be placed on their widest beds, so that they may not be crushed or act as wedges and force out the adjacent work. The side joints should not form an angle with the bed joint sharper than 60°. Some quarries contain stratified stone that can be quarried so as to have two faces more or less parallel to each other. These flat surfaces should be the beds of the stone. Stronger and better walls can be made with stones of this kind than can be made of stones that have no stratification. Rubblework is generally used for foundations and walls that will not be visible on the outside of the finished building. It is also used for backing more expensive masonry, such as ashlar work, referred to later.

The stones that are generally used for rubblework are those which are easily obtained in the locality. These may be field stones or stone quarried from an adjacent quarry, and may be any of the well-known kinds of stone such as granite, limestone, sandstone, conglomerate, etc.

Rubble is also used for the finished surface of an exposed wall. With care in its erection and by using stone of fine appearance and color it forms a very handsome wall. In this case the joints must be carefully made and the stones arranged in the wall according to some pleasing design.

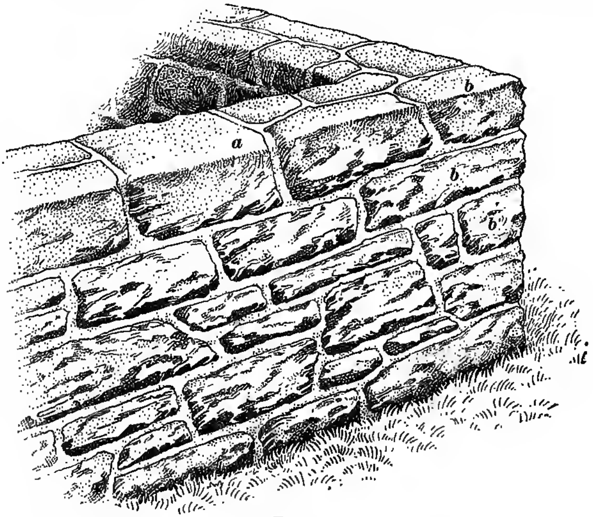


Fig. 9

10. Fig. 9 represents a good type of a rubble wall formed of quarried stone. Where this wall appears above grade, the stones are dressed with some care. This is not necessary where the wall is below grade. The wall is bonded, or tied together, by *bond stones,* as shown at *a* in Fig. 9. One of these bond stones should occur in every 4 or 5 square feet of the exposed surface of the wall. Where the wall is 2 feet or more in thickness, these bond stones generally extend not more than two-thirds or three-fourths of the distance through the wall, as was shown in Fig. 3.

The stones should be laid *breaking joints,* that is, the vertical joints should not be over each other in any two courses, with few exceptions. The stones at the corners of this wall are generally of a longer size and are laid up in alternate courses of headers and stretchers, as shown at *b,* Fig. 9.

The mortar used for all rubblework which is built below the surface of the soil should be a cement mortar with not more than a small percentage of lime mixed with it. A mortar consisting of equal parts of lime and cement may be used for rubble above grade. This is less expensive than cement mortar and is generally sufficiently strong for the purpose.

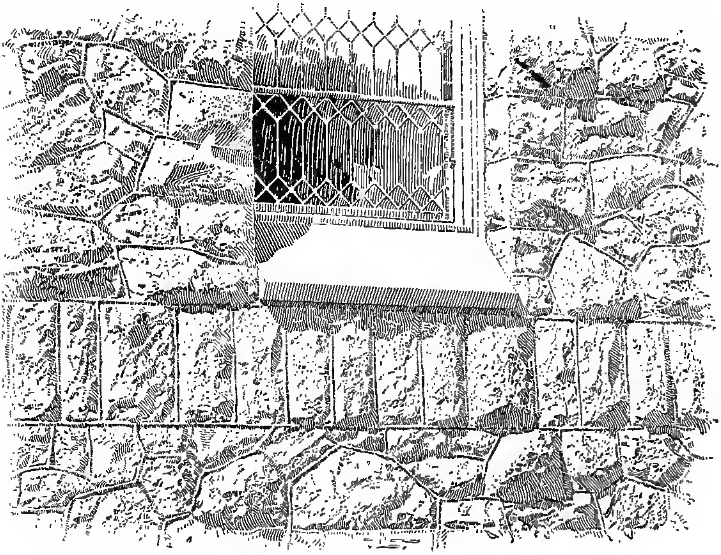


FIG. 10

Owing to the irregular shapes of the stones, cavities are naturally formed in the middle of the wall. These are filled up with mortar and spalls. The bed for each stone should be prepared by filling in any cavities in this manner. The joints at the surface of the wall are frequently pointed with colored mortar and finished with a raised joint.

11. Fig. 10 shows a form of rubble masonry which is very effective for use where the wall is visible. The stones are neatly fitted together, and at the same time the individual stones are irregular in shape. The joints form an irregular pattern over the entire surface of the wall, and should be as nearly as possible of uniform thickness. The individual stones are carefully dressed with a hammer, and no spalls or chips should show in the face of the wall. The work required to dress the stones makes this type of wall rather an expensive one.

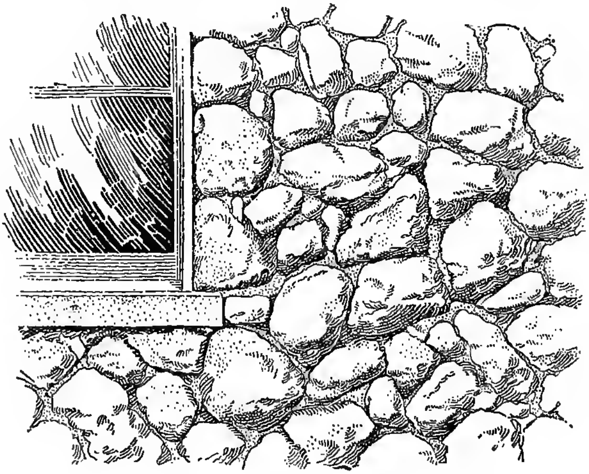


Fig. 11

12. Field-Stone Walls.—Fig. 11 shows a rubble wall built of field stone. The stones for such a wall are collected from adjacent fields and are generally round and irregular in shape. It is necessary, in order that this wall shall have sufficient strength, that a strong cement mortar be used in its construction.

13. Walls With Brick Quoins.—Walls are sometimes built having brick quoins *a*, Fig. 12, at the corners of the wall,

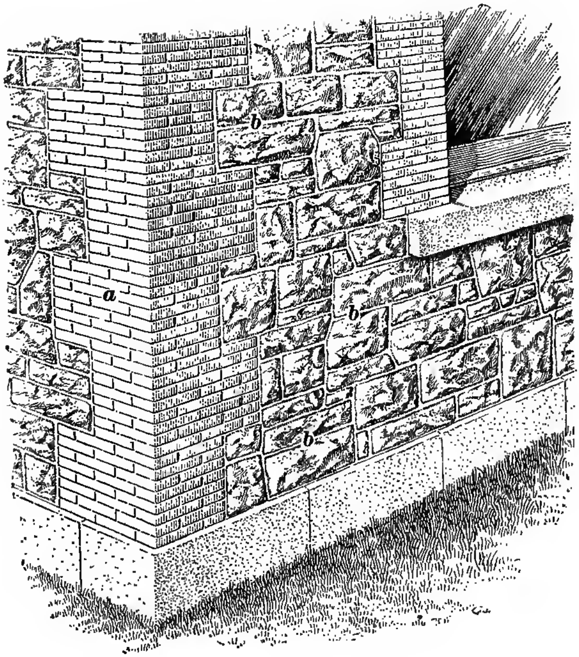


FIG. 12

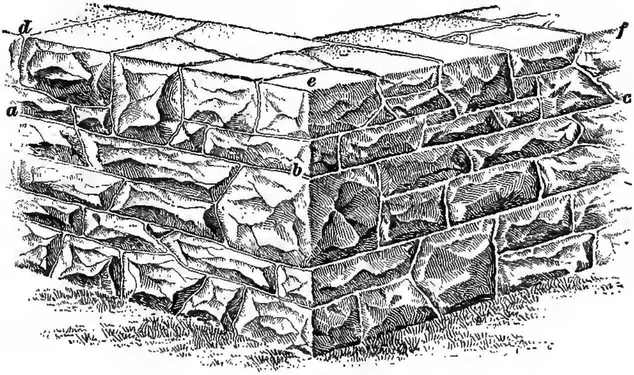


FIG. 13

and also brick quoins around the window and door openings. In the example shown, the top and bottom beds of the stones are level, as at *b, b,* an arrangement cheaply obtained where the stones split readily into layers with parallel beds.

14. Coursed Rubble.—Rubblework is sometimes built in courses between horizontal beds. These courses are from 2 to 4 feet in height, and the masonry is finished by a level bed at this height, and a new course is started at this level. Fig. 13 represents three courses of a coursed rubble wall, two of these beds being shown at *a b c* and *d e f*.

ASHLAR

15. Classification of Ashlar.—Ashlar is a facing made of squared stones, and is used to face brick walls or stone walls of cheaper construction. These brick or stone walls are generally referred to as the backing. The term ashlar is also applied to the stones that constitute this facing. The exposed surface of the stones can be finished in any manner desired, but to be considered ashlar the joints between the stones must

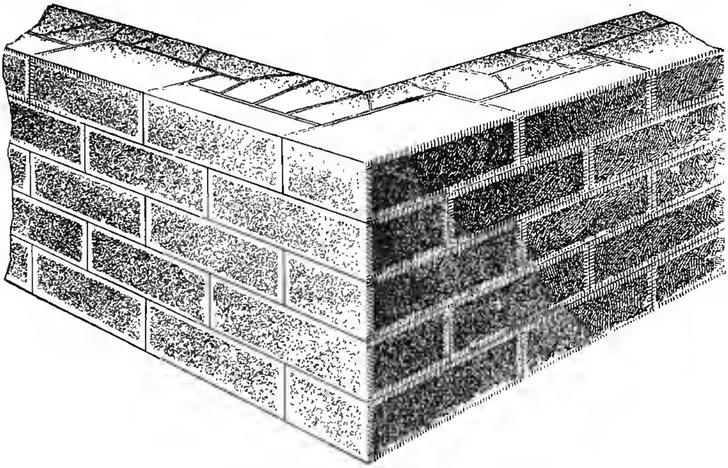


FIG. 14

be horizontal and vertical. There are two general classes of ashlar, namely, *coursed ashlar* and *broken ashlar.*

16. Coursed Ashlar.—Coursed ashlar is that class in which all the stones in each course are of the same height and the horizontal joints are continuous around the building. Good examples of this class of work are shown in Figs. 14, 15, 16, and 17.

In Fig. 14 the stones show equal-size faces in the wall and each stone has a margin or draft line cut around the edges, while the main surface is fine-pointed. In Fig. 15 is shown ashlar in which the courses are in two different heights *a* and *b*, which produces a banded effect. An ashlar wall with elaborately cut quoins and a belt-course is shown in Fig. 16. The quoins and stones of the belt-course are finished in what is called vermiculated work. Work finished in this style is very costly.

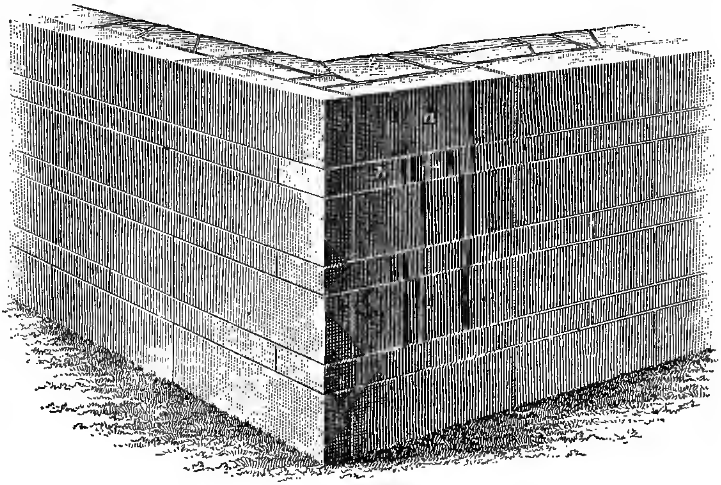


FIG. 15

17. Block-in-Course Ashlar.—In *block-in-course,* or *blocked-course,* ashlar work, shown in Fig. 17, all blocks of stone are cut the same height but in different lengths, and no attempt is made to have the joints come over one another in alternate courses. As a rule, this style of work looks best in rock-faced finish, but any finish desired may be used.

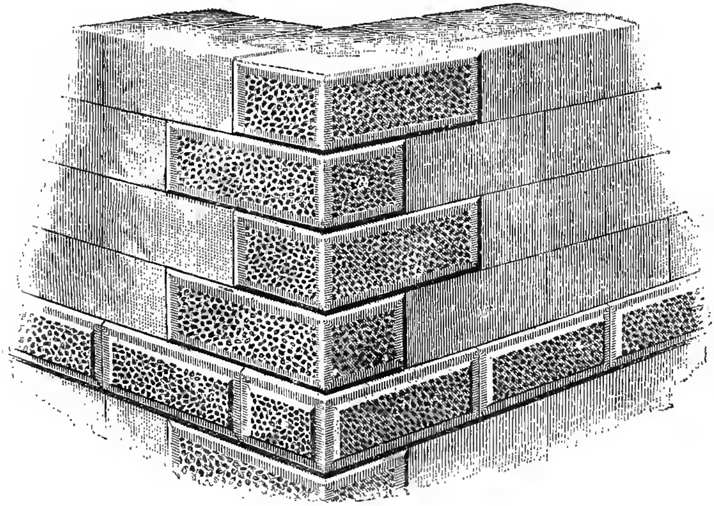


FIG. 16

18. Random-Coursed Ashlar.—The method of laying random-coursed ashlar walls is illustrated in Fig. 18. In this class of work, no attempt is made to have the vertical joints over one another in alternate courses, and it has only a general arrangement in courses, as shown.

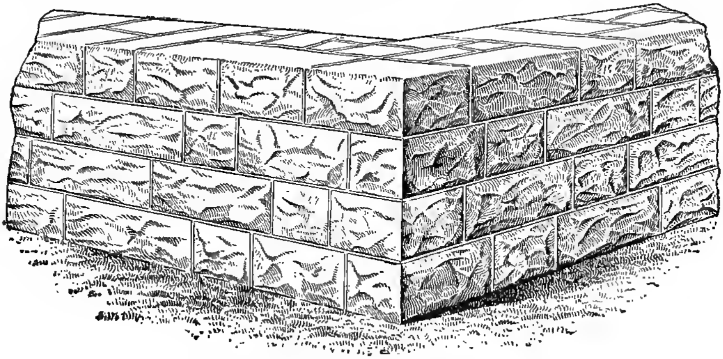


FIG. 17

19. Broken Ashlar.—In **broken ashlar,** sometimes called **random ashlar,** no attempt is made to have the stone run in courses, but each block is cut for the location in which it is to go. It generally takes more time to build the broken ashlar than coursed work, and hence it is more costly, owing to the increased amount of labor required to fit and lay the different sizes of stone. This kind of ashlar, when properly executed, presents a pleasing appearance. It is generally laid up as rock-faced work, but in some cases it is tooled or hammer-dressed. It should have no horizontal joints more than 4 feet long, and several sizes of stone should be used. Fig. 19 shows an ordinary broken-ashlar wall, in which the quoins are indicated at *a* and the ashlar facing at *b*.

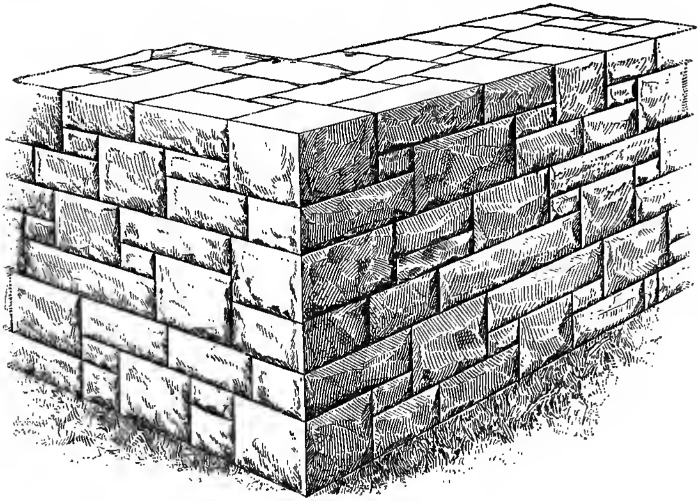


Fig. 18

20. Dressing Ashlar.—Ashlar may be dressed in any of the finishes described and illustrated in the Section on *Building Stone*. Very hard stones, such as granite, trap, etc., are generally given a rock-faced treatment, as elaborate cutting on these stones is very expensive. Granites are, however, sometimes finished with a smooth surface and may even be polished. This finish is used in the lower stories of fine business buildings.

Soft stones, such as limestone, which can be cut readily, are generally finished with 6, 8, or 10 cut work or with rubbed surfaces. Carving is also comparatively cheap when done in soft stones, and when such carving is required soft limestone or sandstone is generally used. Carving done in granite is very expensive.

21. Laying Out Ashlar.—When ashlar in regular courses and sizes is to be used, drawings should be made showing each stone, the heights of the courses, the location of the stones, and other necessary details, as described in the Section on *Building Stone*. The drawings for important buildings usually show every stone. A drawing of this character is shown in Fig. 20. In this drawing it will be noted that individual stones are shown by lines extending from their diagonally opposite corners. These diagonal lines are shown in the rectangular face blocks of the pilaster and on the stones that extend behind the pilaster. The parts of the stones behind the pilaster are indicated by dotted diagonal lines. The stones of

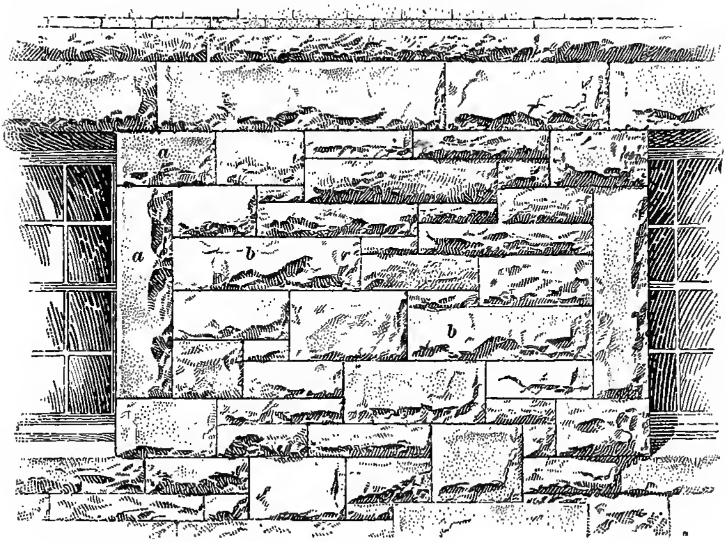


Fig. 19

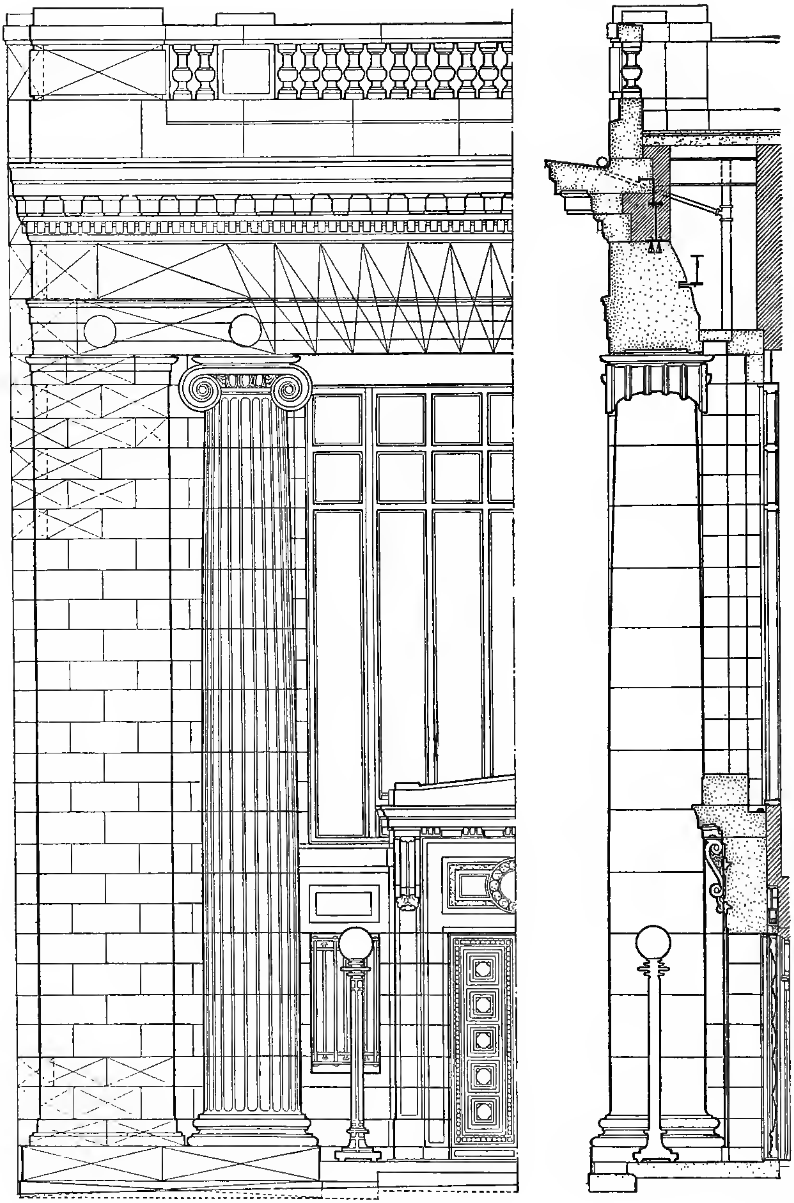


Fig. 20

the flat arch over the opening between the columns are shown by diagonal lines to indicate that they are single stones extending from the top of the column to the bottom of the cornice. When broken ashlar is used, it is only necessary to show the quoins and jambs on the drawings, together with enough of the broken ashlar to indicate the character of the work desired.

22. Backing.—The expense of ashlar masonry is such that it is commonly used merely as a facing, being backed with either rubble masonry or brickwork. In many cases the backing is the real wall and the ashlar is a veneering anchored to this wall, as shown in Fig. 21. In the New York building code, for example, veneering such as shown in (*b*) is not counted in the thickness of the wall when estimating the bearing strength of the wall. If, however, the ashlar is alternately 8 inches and 4 inches thick and is bonded to the wall, as shown in (*a*), it is considered as having a bearing value, and the wall need be made only 4 inches thicker than would be required if the wall were entirely of brick.

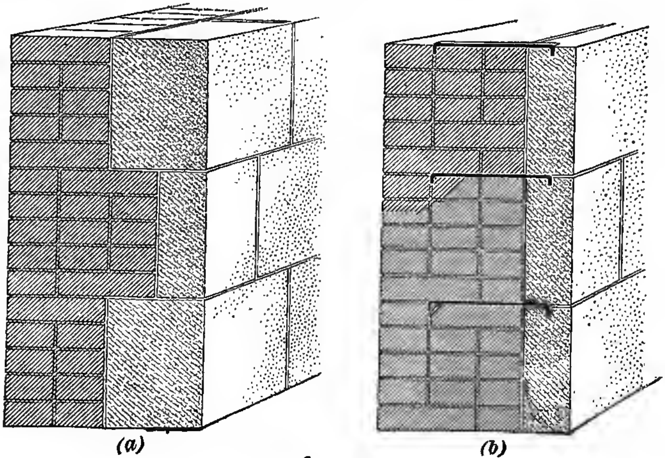


Fig. 21

Both stone and brick are used for backing, but in most cases brick is more convenient, and, hence, is more extensively used. When using brick for the backing, the backing should never be less than 8 inches thick. The backing of ashlar, whether of stone or of brick, should be laid in cement mortar.

When stratified stone with flat parallel beds can be obtained, it can be used to advantage, as it forms a very good backing for ashlar work. Irregular rubble walls should not be used for backing in walls of dwellings higher than two or three stories. All backing, whether of brick or stone, should be carried up at the same time and built in courses of the same thickness as the ashlar in the manner illustrated in Fig. 21.

If the courses are not over 12 inches high, they are usually bonded sufficiently to the backing by making every other course thicker, as in Fig. 21 (*a*).

23. Fastening Thin Ashlar.—Ashlar facing of from 2 to 4 inches in thickness is often used, as shown in Fig. 21 (*b*), especially when marble or other expensive stone is employed in the construction. In such cases, each piece of ashlar should be tied to the backing, in the manner shown, by at least one anchor similar to that shown in Fig. 22. If the stones are more than 3 feet long, two anchors are generally used. All iron clamps, or anchors, should be either galvanized or dipped in hot tar or asphalt, to prevent the formation of rust on them.

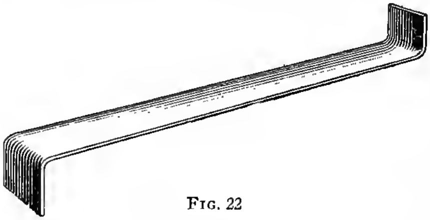


FIG. 22

When a wall is faced with thin ashlar, the effective bearing strength is only that given by the thickness of the brick or stone backing, the facing not being relied on for that purpose.

TRIMMINGS

24. The term **trimmings,** as generally used, includes moldings, belt-courses, sills, caps, and other cut stone (except ashlar) used for ornamental purposes.

The stones for such work should be of good quality, having the beds closely dressed and the ends square and properly matched. All washes, soffits, etc. should be cut smooth or rubbed. When a brick building is trimmed with stone, the stones should be designed so that their height shall be equal to that of two or more brick courses. The horizontal joints of the stonework will then coincide with the horizontal joints of the brickwork. This is important in cases where the brickwork abuts against stone quoins or jamb stones, where it is desirable to have the joints of the brickwork and stonework at the same level. It is equally important that the joints of the backing shall coincide with those of the ashlar, to allow the anchors to extend back into the wall.

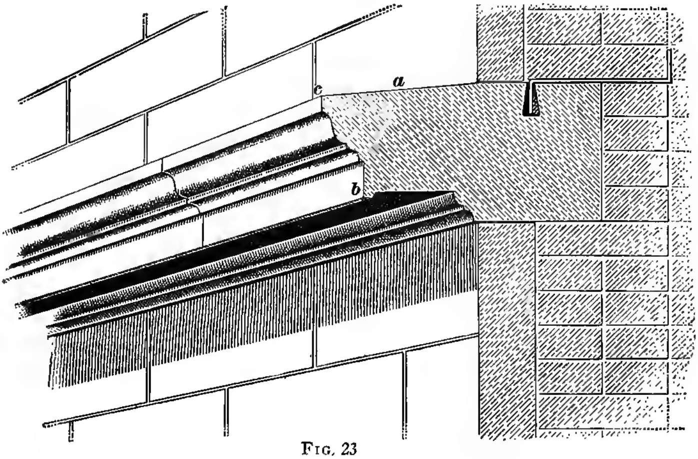


Fig. 23

25. Washes and Drips. The tops of all cornices, belt-courses, etc. should have an outward and a downward pitch from the walls, as shown at *a*, Fig. 23. Such beveled surfaces are called *washes*. If the top

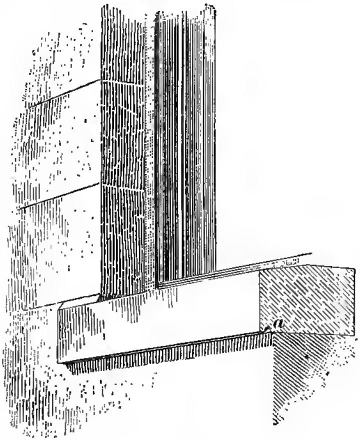


Fig. 24

is level or slopes inwards, water will collect, and in time will cause the disintegration of the mortar in the adjacent joints and finally penetrate the wall. On the under side of the cornices, etc., *drips* should be made, to prevent rainwater from flowing down the face of the wall. Such a drip is shown at *b*, Fig. 23.

Window sills should also have a drip cut in them, as shown at *a* in Fig. 24, to keep the walls below from becoming discolored by dirt washed off the sills by rain.

LINTELS

26. A **lintel** is a stone that supports the wall over a door, window, or other opening, and it sometimes bears a considerable load and should therefore be a strong and durable stone of ample size. Frequently, however, the lintel is made very thin and is not designed to support the wall above, this work being done by steel beams. The ends of the stone lintels should not be built into the walls more than is necessary to give sufficient bearing, 4 to 6 inches at each end being the usual allowance.

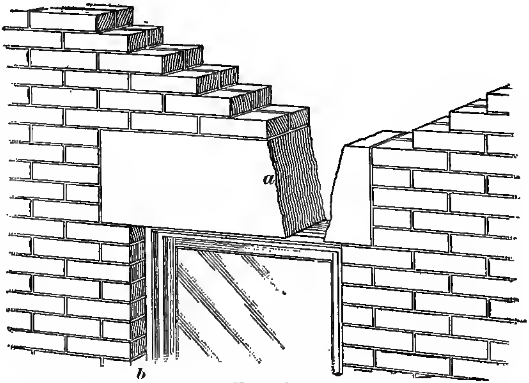


FIG. 25

27. A lintel may sometimes extend throughout the full thickness of the wall, as shown at *a* in Fig. 25, but ordinarily a lintel is made of the same thickness as the depth of the **reveal,** or exposed jamb of the window, *b*, which in the case of a brick wall is about 4 inches, or the width of one brick. Where the wall is built of stone this reveal may be 6 inches, 8 inches, or more in depth, and the lintel is made of a corresponding thickness. In such cases a lintel of steel or a brick arch is placed behind the stone lintel, to support the remaining thickness of the wall above. Thus, if the wall is a 16-inch wall, and the reveal and lintel are each 6 inches, the wall to be supported by the steel lintel or brick arch would be 16−6=10 inches.

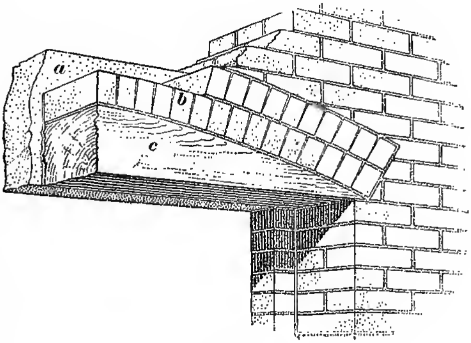


Fig. 26

In Fig. 26 is shown an example of a stone lintel *a* backed up by a brick arch *b*. This brick arch rests on the wooden center, or support, *c*, which serves to support the arch until the mortar has set, after which the arch itself will be strong enough to sustain the wall over it, taking most of the load from the lintel. Such an arch is known as a **relieving arch.** A double rowlock arch, such as shown at *b*, is strong enough for a door or window opening that is not over 3 feet in width. For an opening of from 3 to 4 feet in width three rowlocks should be used. Fig. 27 shows a section through the arch illustrated in Fig. 26. Steel is used instead of relieving arches for openings greater than 4 feet in width.

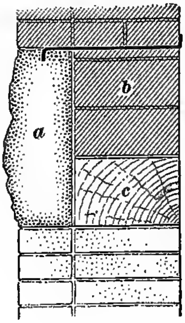


Fig. 27

In Fig. 28 is shown a stone lintel *a* and a steel lintel *b*. The steel lintel consists of two angle irons which support the inner portion of the wall above the opening. The brickwork is built directly on the flanges of the angles, which serve the same purpose as the brick arch shown in Fig. 26.

28. I-Beam Supports.—Where the opening is quite large and a stone lintel is not sufficiently strong to carry its part of the load, the lintel is often supported upon I beams as shown in Fig. 29. The steel beams are shown at *a*, and the stone lintel is shown at *b* and rests upon the plate *c* which is riveted to the bottom flange of the outer I beam. The stone is sometimes cut so as to receive the plate and conceal its front edge. The steel plate should extend to within about 1 inch of the face of the lintel and the lintel should be anchored at the top by an anchor. A considerable load can be supported upon a construction of this kind. The stone, however, does not support any of the load, but is a mere facing.

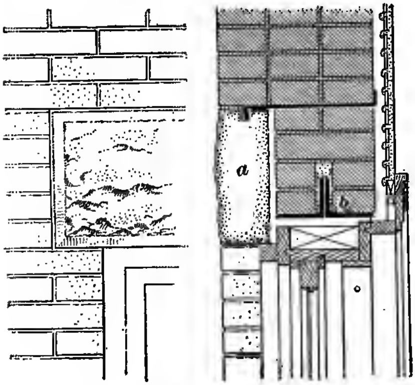


Fig. 28

Floorbeams are frequently supported upon lintels such as just described and may rest directly upon the **I** beams, as shown at *d*, or upon one of the brick courses immediately above the **I** beams.

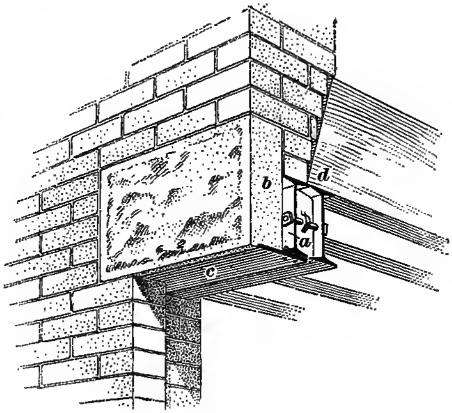


Fig. 29

It is not good practice to support the weight of a wall on both stone and steel or wooden beams, as the deflection of each material is different, making it practically impossible for each to carry its proper share of the load. The weight should preferably be borne by the steel alone, as shown in Fig. 29.

29. Built-Up Lintels.—It is sometimes necessary to use a stone lintel 10 or 12 feet long, which is difficult to obtain in a single piece. In such a case, the lintel may be made in sections, and the joints made to resemble those of an arch, as shown at *a* in Fig. 30. A stone lintel of this description is generally supported upon a steel lintel as shown at *b*, and each stone is anchored by an anchor as at *c*. The stone lintel in this case is merely the facing for the steel lintel and has no supporting value. The same treatment is used when a flat arch of brick, instead of stone, is used.

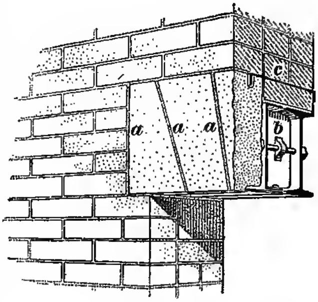


FIG. 30

SILLS

30. Lug Sills.—In masonwork, sill is the name given to the stone that forms the bottom of a window or door opening in stone or brick walls.

Lug sills, as shown in Fig. 31, have ends *a*, called *lugs*, built into the wall. These lugs should enter the walls from 2 to 4 inches, and the sill should be bedded in mortar only at the ends. If a sill is bedded solid and settlement occurs, it will probably be broken, as the pier or side walls will likely settle more than the wall under the opening. The bed joints under the sills, between the ends, should be filled when the finished walls are cleaned down. In very long sills these joints may be filled with hair felt set in the bed with a calking iron. Such a filling is weather-proof and yielding.

31. Slip sills are made just the width of the opening, and are not built into the walls. Slip sills are cheaper, but do not look so well as lug sills; besides, there are exposed vertical joints at the ends into which water is apt to penetrate. Settlement of the masonry is not liable to break a slip sill, and hence they are often used in the lower parts of heavy buildings.

32. All sills should have a bevel, or wash, of about 1 inch to the foot, extending to the back of the stone, as shown in Fig. 31. They sometimes have a straight beveled surface the full length of the sill, the lugs being omitted and the brickwork being made to fit the stone. This, however, is not good practice, as the sloping upper face forms an insecure bearing for the wall resting on it. In Fig. 31 is shown the proper method of cutting the surfaces: *a* indicates the end of the lug sill, carrying the brickwork reveal *c*; *b* shows the bevel, or wash; and *d*, the drip.

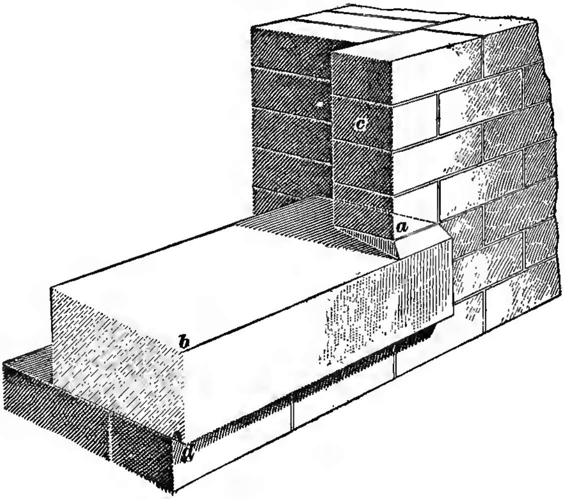


FIG. 31

COPING

33. Coping Stones.—If no cover is put on the top of a wall, water will enter the joints between the brick or the stone. For this reason, parapet walls and those constructed in a similar manner are capped with wide stones called coping. Terra cotta and concrete are also used for this purpose. The upper surface of the coping should be pitched as shown in the upper illustrations in Fig. 32, and there should be drips on the under side as shown. Sometimes a flat flagstone is used as a coping, as shown in the lower illustration, where *a* is the stone and *b* the drips. The coping should project $1\frac{1}{2}$ inches or 2 inches over each face of the wall. To prevent them from becoming displaced, horizontal coping stones are often clamped together at their ends, as at *c*. They may also be doweled together with metal dowels as at *d* or with stone dowels as at *e*.

The joints should be carefully filled to prevent water entering them. Cement mortar consisting of one part Portland cement and one part sand should be used and the joints finished off even with the surface of the coping.

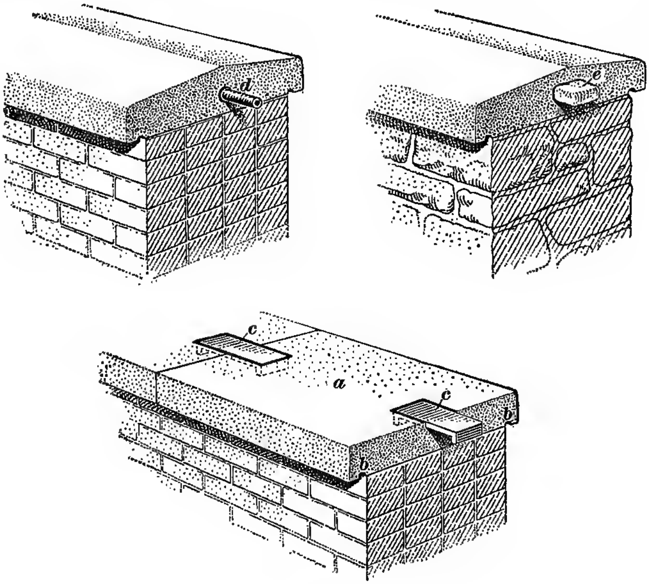


FIG. 32

34. Gable Copings.—Copings are used to protect the inclined upper surfaces of gable walls, as shown in Fig. 33. It is necessary to secure these stones to the wall very carefully, as there is a tendency for them to slide down the wall. They are secured by the use of *kneelers a, bond stones b,* and *anchors c.* The kneeler is cut with a long horizontal bed and prevents the section of coping *d* from sliding. The bond stone *b* is cut so that it will extend into the wall and receive the end of the anchor *c*, which is turned down into the top of the stone. The other end of the anchor is turned up into the body of the gable wall. The coping stones are held together so that they cannot move sidewise by means of dowels *e*, which are made of pieces of metal rod, or else by clamps as shown at *c* in Fig. 32. The fewer joints that are used in coping of any kind the better. Great care should, however, be exercised in bedding very long stones or they may break.

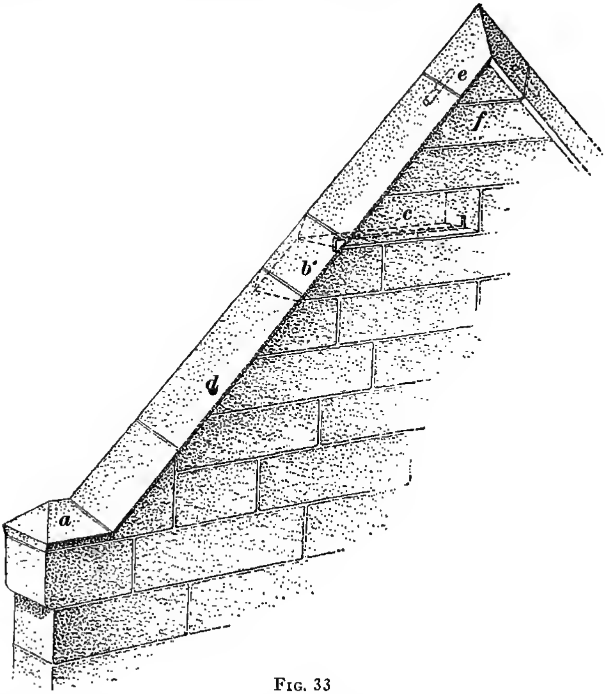


Fig. 33

35. Gable copings need not be pitched on the upper surface, but should project for an inch or two over each face of the wall and have a drip at each edge so as to shed the rainwater. The coping at the point or apex of a gable wall is sometimes finished with a single stone which has a flat bed, as at *f*, Fig. 33, and is doweled into the stones on each side of the gable. A *finial,* shown in Fig. 34, is sometimes used to terminate the gable when an ornamental effect is desired. This finial is cut out of one piece of stone and the two faces are sometimes grooved to receive the coping stones as shown at *a*.

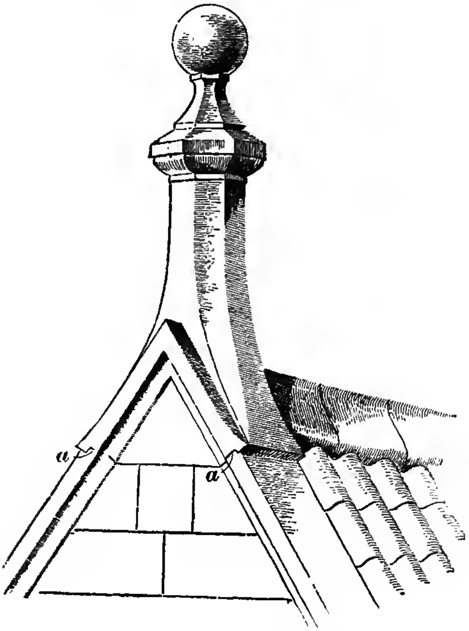


FIG. 34

COLUMNS AND ENTABLATURES

36. Columns.—Columns of stone that are not more than 8 or 10 feet in height are best made with the shaft in one piece, each shaft being a *monolith*. The capitals and bases are generally made of separate stones. Larger columns are made up of sections called *drums,* shown in Fig. 35 at *a, a*. The shafts of large columns that are intended for monumental purposes are sometimes made in one piece, or monolithic. This work is, however, very expensive and is not done except in monumental work.

When a column is to be formed of several pieces, the stones composing the different parts should be very carefully cut, having the beds between the cap, base, and shaft perfectly plane

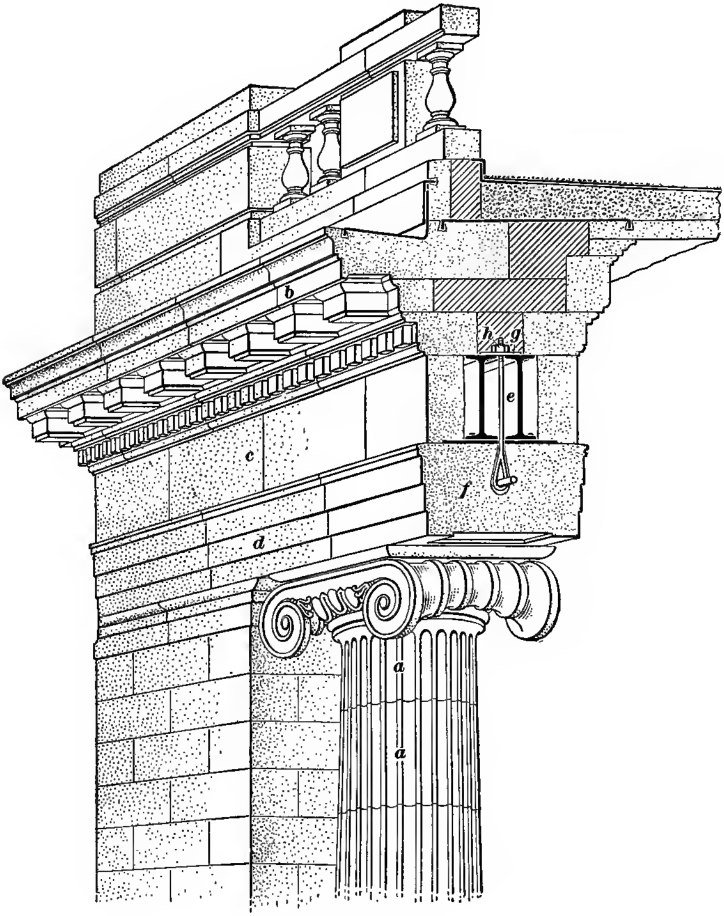


Fig. 35

and perpendicular to the axis of the column, in order that the pressure may be evenly distributed over the entire surface of the joints, also so that the stones shall fit exactly when put in place. For the joints, nothing but cement mortar should be used, which should not be allowed to come within $\frac{3}{4}$ inch of the edge of the joint, in order to prevent the edges of the stones from spalling. After the column has been finished for some time these joints are pointed up with strong mortar.

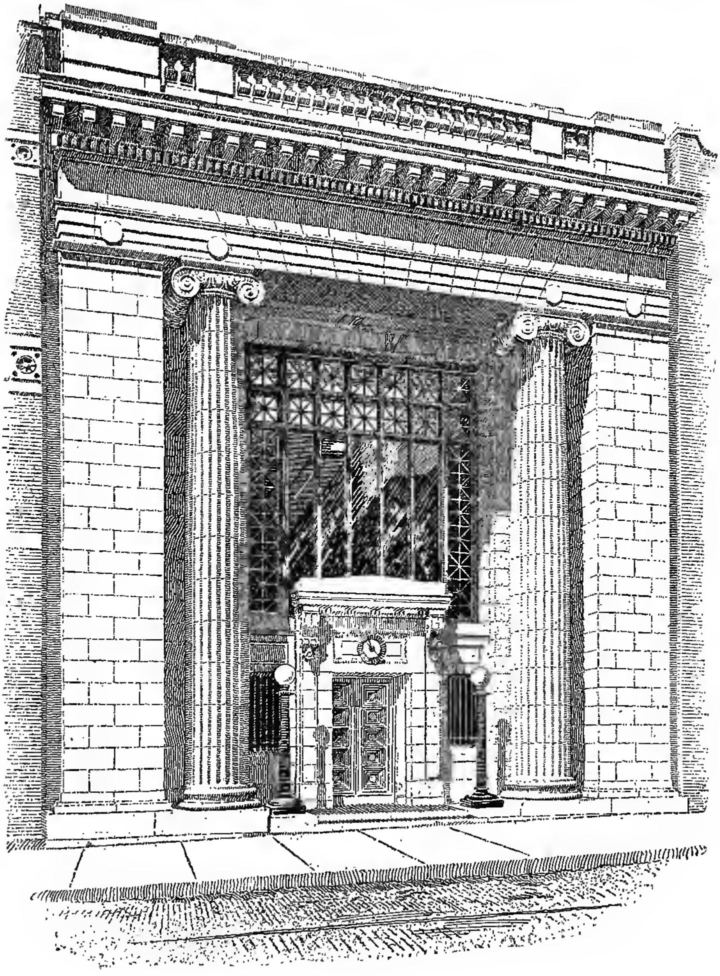


Fig. 36

Columns generally have what is called an *entasis,* or swelling, in the shaft, as shown in Fig. 36, and must be laid out with extreme care so that the drums shall fit together properly when the column is erected.

37. Pilasters.—A pilaster is a projection, rectangular in horizontal section, which projects from the face of a wall and has a capital and base similar to those of a column. Pilasters are tied into the masonry of the wall by extending occasional stones back into the wall.

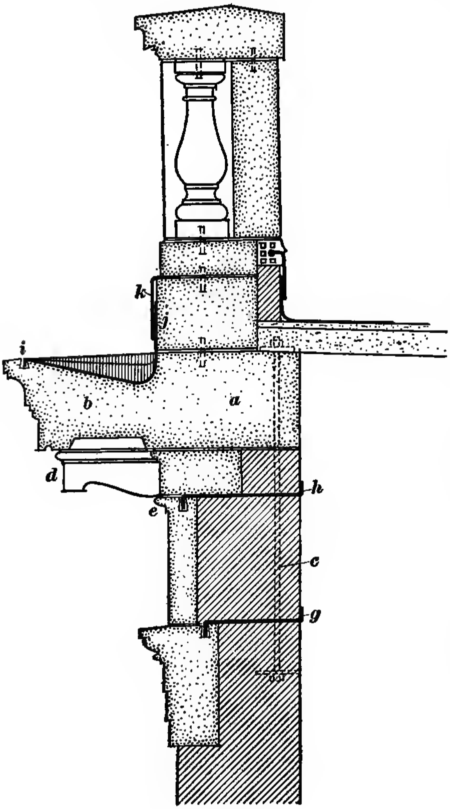


Fig. 37

38. Entablatures. An entablature is an ornamental projecting band that crowns the building or some portion of the building, such as the main entrance or porch. It is generally used over columns and pilasters and consists of three parts, called the *cornice,* shown at *b,* Fig. 35, the *frieze,* shown at *c,* and the *architrave,* at *d.* The cornice has a projection about equal to its height and in certain cases is used without the other parts of the entablature.

An entablature such as is used on the face of a building is shown partly in section in Fig. 37. This cornice has a projection equal to its height and must be constructed so that the projecting part will not fall into the street. As a rule, these projecting stones are balanced by having at least an equal weight of stone extending into the wall as shown at *a*. The weight of the portion of the stone *a* to the right of the face of the wall is slightly greater than that of the portion *b*. In addition to this precaution these stones are sometimes anchored down into the masonry by means of steel rods *c*, which extend up between the joints of the stones and down into the solid masonry and have steel washers on each end to form an anchor. The bracket course is shown at *d* and the bed moldings at *e*. The stones in the course *d* are held in place by being well balanced on the wall below and by the stone *a b* above.

The frieze is made of a thin stone which is held in place by means of the anchor *h*. The architrave is well supported and is anchored as shown at *g*.

39. An entablature acting as a lintel is shown in Fig. 35. The distance between columns is too large to be spanned by a single stone, consequently a steel girder is used to support the entire entablature and balustrade above. This steel girder, consisting of two **I** beams, is shown at *e*. The stones of the architrave beneath are hung from the girder by rods which pass between the joints and are secured to bars or rods of steel that are let into the ends of the adjacent stones. The upper ends of the rods pass through small plates, as at *g*, and are held by nuts *h*, that are screwed up until the stones are supported at

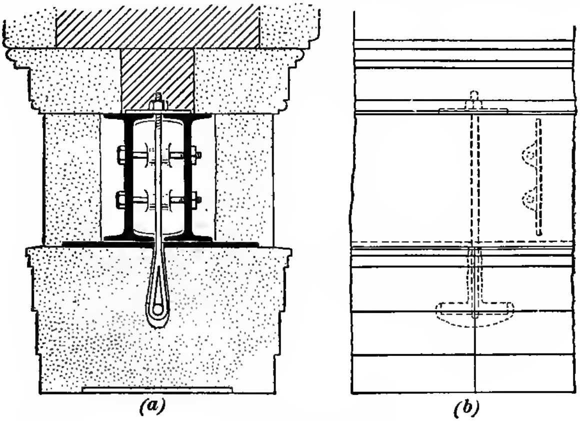

(*a*) (*b*)

FIG. 38

the correct level. This construction is shown in detail in Fig. 38, in which a cross-section is shown in (*a*), and a section showing how the hanger supports the stones is shown in (*b*).

40. In Fig. 37 is shown one method of forming a gutter in the stone cornice. The stone is cut so as to form a gradual pitch from one end to the other and is lined with copper. The copper is left into a *reglet,* or groove, *i* and is held in place by calking with lead. The other edge is turned up against the surface *j* formed in the stone and a counterflashing *k* is brought down over the flashing.

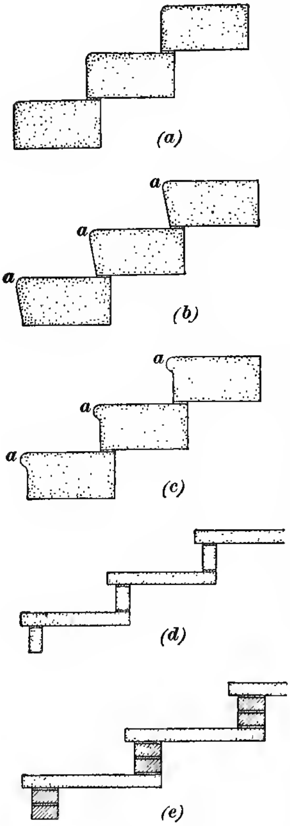


FIG. 39

STONE STEPS AND PLATFORMS

41. Stone Steps.—Stone steps are used as entrance steps for public buildings, schools, fine houses, and in other places where a monumental appearance is desired. They are also used in rustic work such as shown in Fig. 42 where suitable stones can easily be obtained. They should be made of the hardest stones obtainable, such as granite, bluestone, or marble. Limestone and sandstone are also employed where they are conveniently obtained, and they make serviceable and handsome steps. They show the effects of wear more quickly, however, than the harder stones do.

Stone steps, especially on public and monumental buildings, should be made of such a size that walking up and down them will be easy. A good average size for the tread is 12 inches and for the riser 6 inches. If the tread is narrower, the riser should be increased in height. The steps will be easy if the height of the riser in inches multiplied by the width of tread in inches equals 72.

The steps should be finished with a slightly roughened surface so as to prevent slipping and should have a slight pitch downwards toward the front so that water will readily drain off them.

42. Forms of Steps.—Steps are made of solid pieces of stone, and of thin slabs. The solid steps are the best from the standpoint of appearance and service. Stone steps are made of blocks of rectangular sections, as shown in Fig. 39 (*a*), (*b*), and (*c*), and are finished square as in (*a*) or with *nosings* as shown at *a* in (*b*) and (*c*). Steps are formed of thin slabs of stone, such as marble, bluestone, etc., as shown in (*d*) and (*e*). In (*d*) the risers as well as the treads are formed of stone, which should be about 2 inches in thickness and held in place by having the ends inserted into side walls or else by being anchored to a backing. In some cases the risers are made of brick, as in (*e*).

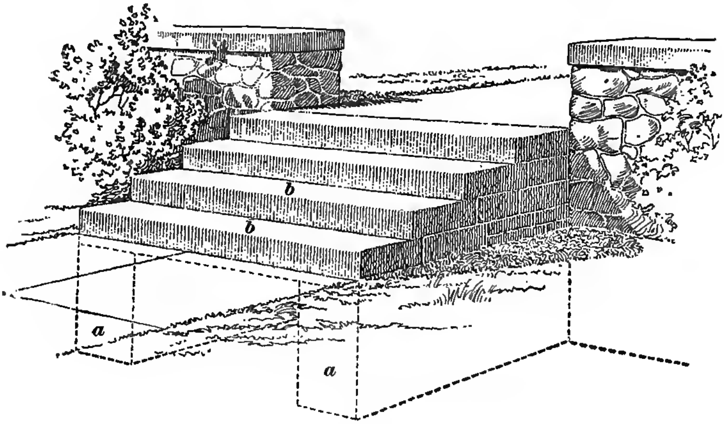


FIG. 40

In all cases the edge of the tread should be rounded off slightly and all the treads should be laid so that there will be a slight pitch downwards from the back to the front of the tread.

43. Supporting Stone Steps.—Stone steps are supported in different ways. The simplest is upon walls that are built under the steps at each end and upon which the steps rest. This method is illustrated in Fig. 40, in which *a, a* are the walls supporting the steps *b*. The supporting walls must be started below the frost line and be built so that no settlement shall occur.

44. These walls are often carried up to form *cheek* walls as shown at *a* in Fig. 41. The ends of the steps are let into the cheeks from 4 inches to 6 inches so as to have a sufficient bearing. When the distance between the bearing, or cheek, walls is more than 5 or 6 feet, it becomes necessary to make the steps two or more pieces in length. In this case intermediate walls are built to support the steps, as shown at *a* in Fig. 42. It is not desirable to provide only one intermediate support, as the joints of the steps would come too close together, hence two or more of these intermediate walls are built, depending upon the width of the steps, so that the joints may alternate over them as shown at *b, b,* etc. These walls should be not more than 3 or 4 feet apart.

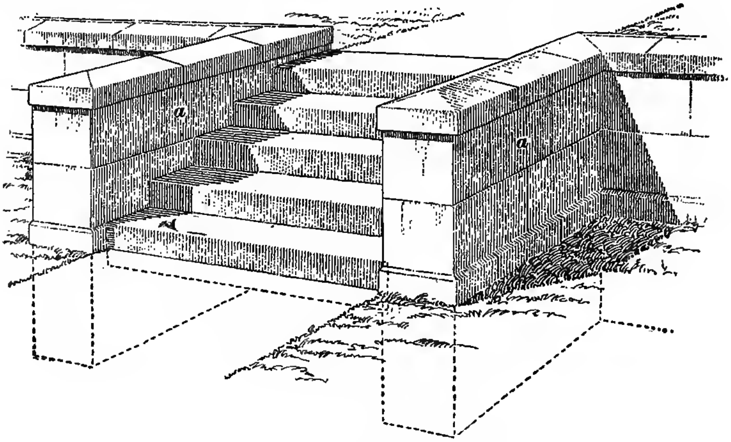


Fig. 41

In the example shown in Fig. 42 the treads are formed of slabs of stratified rock and the risers are of brick. Nevertheless the stone treads support the structure, since they extend under the brick risers and hold them up. This is illustrated at *c*, where an intermediate wall *a* is shown supporting the steps and the treads are shown resting upon this wall with brick risers on top of them. The pier *d* must be made of a size that will give support to the ends of the steps at *f*, and both the piers and the walls should be begun below the frost line. Some of these steps are shown resting on cheek walls *e*, and some of them resting only upon walls *a*, *a* and *d*. The finished grade around the bottom step is indicated by the dotted line *g*.

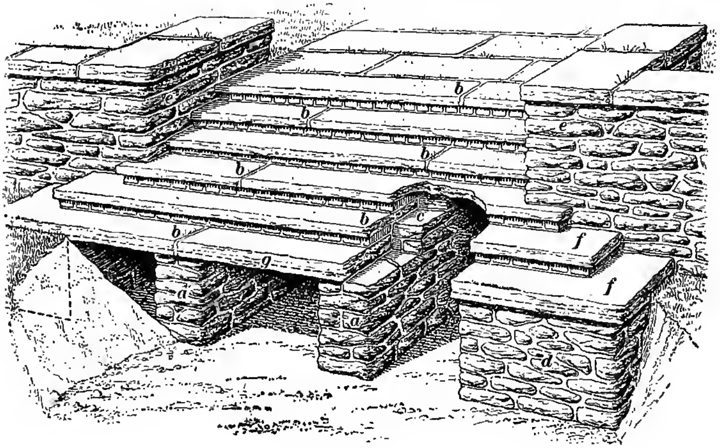


FIG. 42

45. In Fig. 43 is shown another method of supporting stone steps. The foundation for the steps, in this case, consists of cheek walls *a* for the ends and walls *b* and *c* under the top and bottom of the flight. An inclined reinforced-concrete slab *d* is supported on the walls *b* and *c*, and rough masonry *e* is built up on top of this slab to support the portion of the steps between the cheeks. This method is particularly useful when space beneath the steps is to be used for a storage or coal vault, as the slab *d* forms a good ceiling for such a vault as well as a support for the steps.

46. Platforms.—Platforms are formed between two short flights of steps and must in general be supported in a similar manner to the steps. Platforms are generally of single slabs and these are sometimes of a good size, often as much as 6 feet square. They should not be made too thin, as they are liable to be broken in handling. The thickness of a solid stone platform should in general be equal to the height of a riser but should never be less than 5 inches.

47. Iron staircases are extensively used in fireproof construction. The treads, and sometimes the risers, are frequently marble slabs, while slate, which is cheaper, is also considerably used. When so used the stone treads should be set upon a sheet-metal tread so that if they are cracked or broken by the action of fire there will be a sheet-metal tread to walk upon.

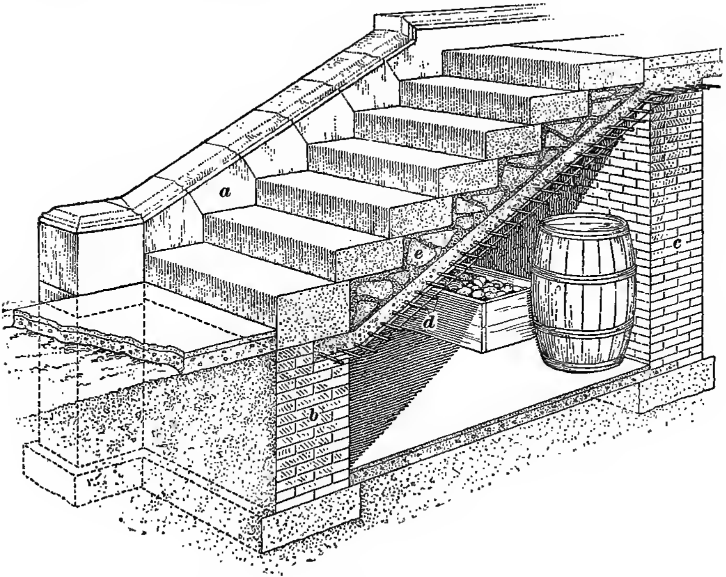


FIG. 43

STRING-COURSES, OR BELT-COURSES

48. A **string-course,** or **belt-course,** is a course of stone which generally projects or is ornamented in some manner so as to make a distinct horizontal band around the building

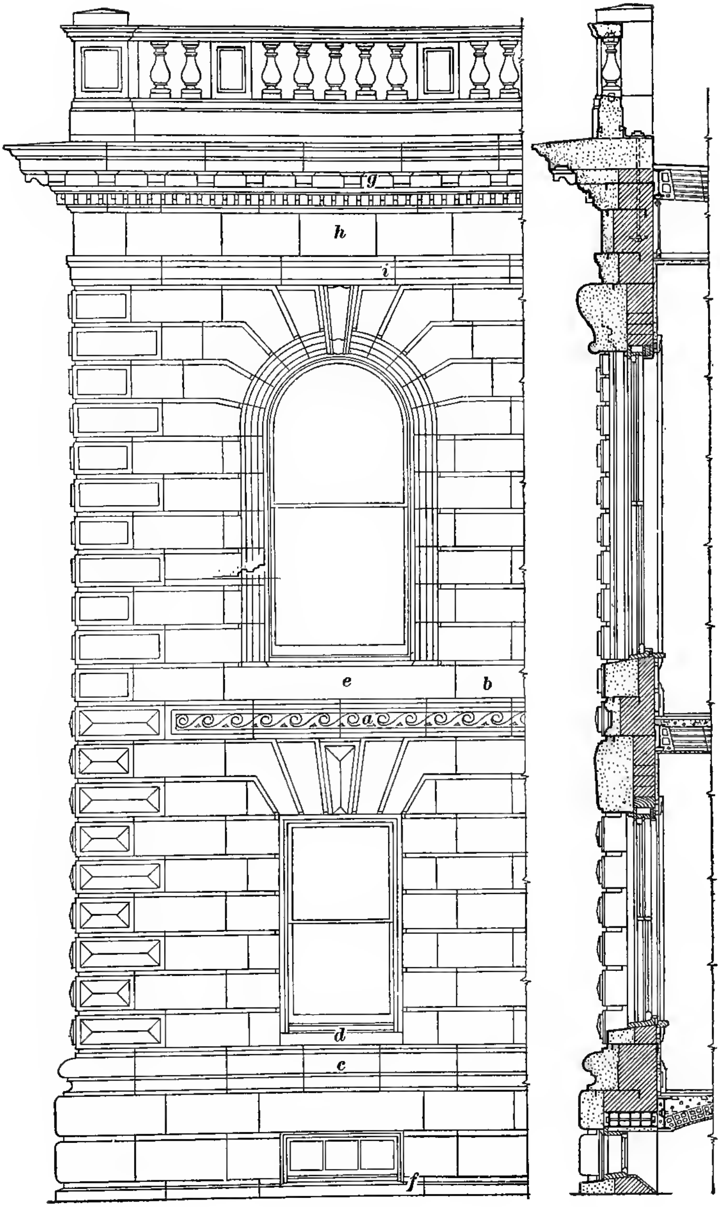


Fig. 44

or, in many cases, across the front of a building. Such a string-course is shown at *a* in Fig. 44. This string-course projects and is also ornamented and is carried around the building to mark the level of the second floor. The course *b* is what is sometimes called a *sill-course* since all the sills of the second-story windows are included in it. A string-course which is known as a **water-table,** and which forms the top of the basement wall, is shown at *c*.

This figure also illustrates several of the features of stone masonry that have already been discussed and shows their application to the façade of a building. The façade is faced with rusticated coursed ashlar. Ornamental quoins are shown on the corner of the building. A slip sill is shown at *d* and lug sills at *e* and *f*. An example of an entablature, consisting of the cornice *g*, the frieze *h*, and the architrave *i*, is shown. In the section the backing of the wall is shown by the hatched surface.

STONE ARCHES

49. Definition.—An **arch** is a masonry construction consisting of a series of individual stones which are used to span openings in walls or between piers or columns. Arches of various types are illustrated in Figs. 45, 47, 49, etc.

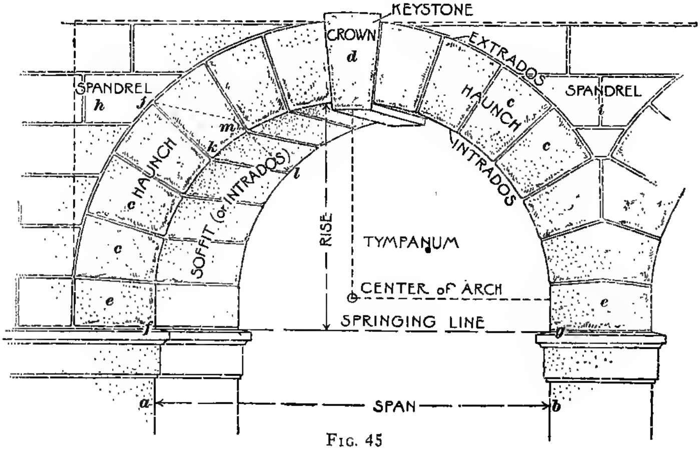


Fig. 45

The general forms of arches are *semicircular, segmental, pointed, elliptic,* etc., the name being determined by the shape of the inner curve of the arch.

50. Parts of an Arch.—In order to obtain a better understanding of arches, the following definitions of the various parts of an arch are given. They may be readily understood by referring to Fig. 45.

Span.—The horizontal distance between the supports, as shown at *a b.*

Springing Line.—A line drawn through the points where the arch meets the abutments or supports, or where the vertical supports of the arch terminate and the arch begins, as shown at *f g,* Fig. 45.

Rise.—The perpendicular distance from the springing line to the highest point of the intrados.

Crown.—The highest portion of the arch.

Intrados.—The lower concave surface of the arch, formed by the under side of the stones, although considered by some authorities to be the concave line at the edge of the under side of the stones.

Soffit.—The lower surface of the arch, or the intrados.

Extrados.—The upper convex surface of the arch, formed by the outer sides of the stones in the arch; also, considered by some authorities as the convex line of the outside of the arch.

Arch Ring.—The arch itself, contained between the intrados and the extrados.

Skewback.—A stone in the abutment having an inclined face from which a segmental or flat arch springs. Skewbacks are shown at *a, a,* in Figs. 47 and 49.

Haunches.—The portion of the arch included between the crown and the springers.

Voussoirs, or Ring Stones.—The wedge-shaped stones *c,* Fig. 45, composing an arch.

Keystone.—The center or highest voussoir, shown at *d,* Fig. 45.

Springers.—The lower voussoirs, or bottom stones, *e* of an arch.

Tympanum.—The space between the springing line and the intrados.

Spandrel.—The triangular wall space *h,* Fig. 45, included between the extrados, a horizontal line drawn through the top of the extrados, and a vertical line drawn through the lower extremity of the extrados; or the space between two arches in an arcade, as shown at *i.*

Spandrel Filling.—The stonework filling the spandrel.

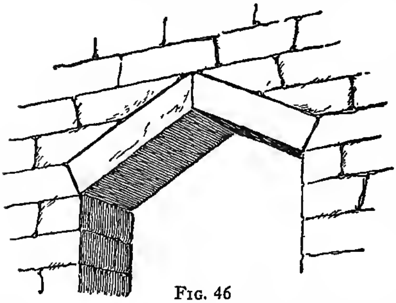


Fig. 46

51. Stability of Arches.—The action of the load on the extrados of the arch presses all the voussoirs toward the center of the arch, which causes the voussoirs to press against each other. The surfaces under pressure, such as *j k l m,* Fig. 45, must be of sufficient size to sustain the pressure of the voussoirs upon each other. It is found in practice that an arch that looks well is generally of sufficient strength. An arch fails either by crushing of the stones or by the displacement of the stones due to unequal loading.

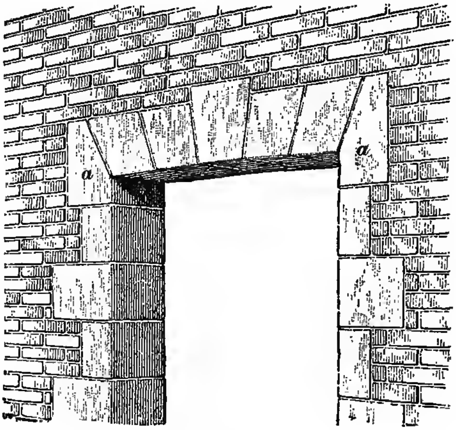


Fig. 47

52. Kinds of Arches.—Arches are named, from the form of the intrados, *semicircular, segmental, semielliptic, pointed, flat,* etc. The arch shown in Fig. 46 is an old and primitive form of arch. It is probably the first form of arch ever built.

53. Flat Arches.—The arch shown in Fig. 47 is known as a flat arch, and is very simple in design. This style of arch is used extensively over windows and other short spans where a flat soffit is desired, and very often in brick buildings. It will be noticed that all the voussoirs are wedge-shaped and that it would be difficult to force any one down out of its place. Although called a flat arch, it is usually built with a rise of $\frac{1}{8}$ inch per foot of span. For example, if a flat arch, such as shown in Fig. 47, has a span of 5 feet, the soffit will be $5 \times \frac{1}{8} = \frac{5}{8}$ inch higher at the center than at the sides of the opening. The rise in this case is $\frac{5}{8}$ inch. This rise is to allow for any settlement that might occur in the arch. It also adds to the appearance of the arch, as an absolutely flat arch always has the appearance of sagging at the middle, whereas, a slight rise tends to neutralize this effect. A flat arch treated in this manner is said to be *cambered.*

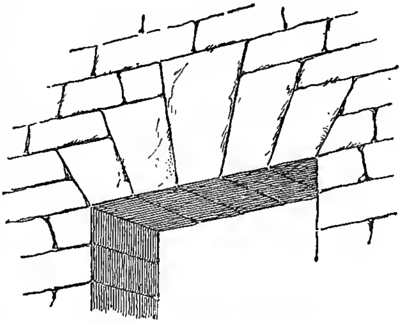


Fig. 48

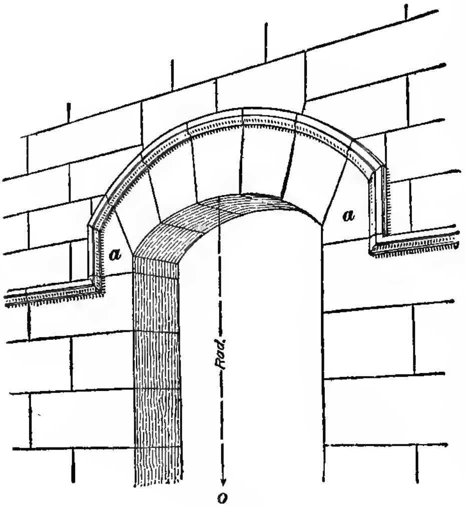


Fig. 49

54. Fig. 48 shows another style of flat arch, in which the voussoirs are of different sizes. There are other styles of flat arches used in practice, but they are all built on the same principle as those just described.

55. Segmental Arches.—If the intrados of an arch is in the form of a segment of a circle, as shown in Fig. 49, the arch is called a *segmental arch*. The curve of the intrados is struck from a center, as *o*. The point *o* is always below the springing line in an arch of this character, and the radius of curvature of the intrados is always greater than one-half the

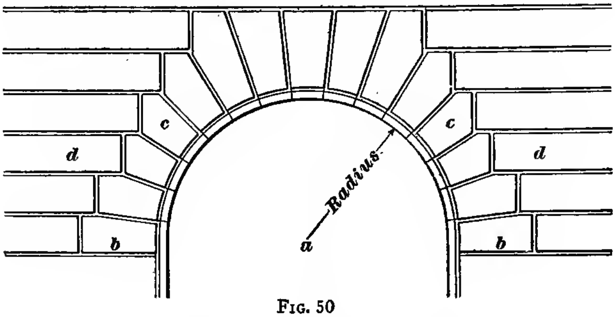


FIG. 50

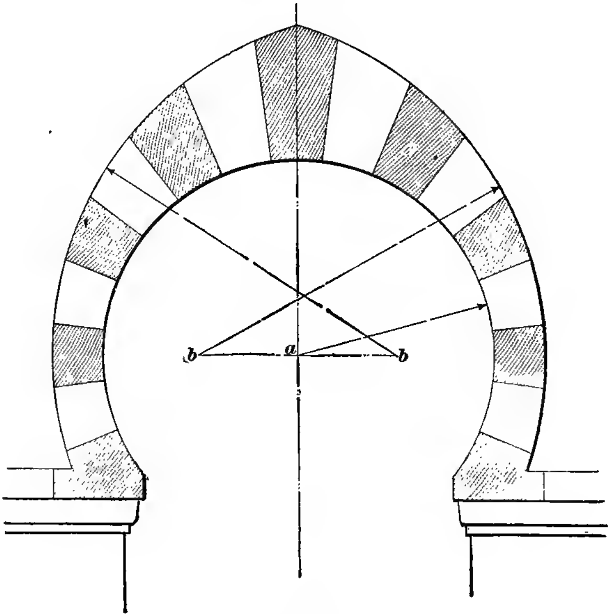


FIG. 51

span. The curve of the extrados is usually drawn from the same center as the intrados, although this is not necessary. In this example the arch springs from the skewbacks *a*.

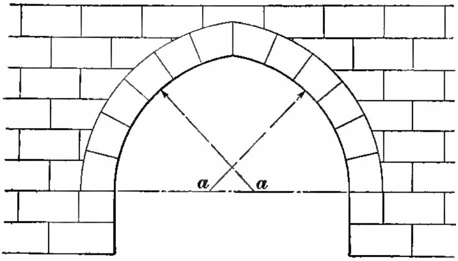


FIG. 52

56. Semicircular Arches.—When the intrados of an arch is a full semicircle with a radius equal to one-half the span of the arch, the arch is known as a *semicircular arch*. Such an arch is illustrated in Fig. 50. This type of arch is frequently referred to as a *circular arch*. In Fig. 45 the arch ring is of equal depth all around and the voussoirs are all of the same size, while in Fig. 50 the voussoirs are of different shapes. This is a matter of design only and has no particular constructional value.

57. Moorish Arches.—Fig. 51 shows an example of a Moorish, or horseshoe, arch. In this arch the intrados forms a curve that is greater than a semicircle. The centers of this arch are shown at *a* and *b*, *a* being for the intrados and *b* for the extrados.

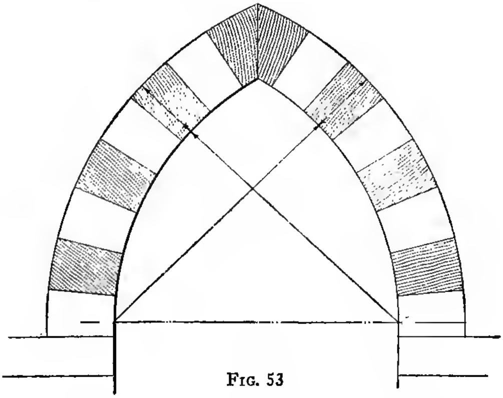


FIG. 53

58. Pointed Arches.—Pointed arches are illustrated in Figs. 52, 53, and 54. Fig. 52 shows a rather wide form of pointed arch that is sometimes called a *two-centered arch.* This arch has two centers, as shown at *a, a,* and the length of the radius is less than the span of the arch, and greater than one-half the span.

In Fig. 53 is shown what is known as an *equilateral arch,* in which the length of the radius is equal to the span of the arch.

59. The *lancet arch,* shown in Fig. 54, is one in which the radius is greater than the span of the arch, the centers generally being outside of the arch, as shown at *a, a.*

60. Semielliptic Arches.—Where the arch has an intrados in the form of a semiellipse, it is known as a *semielliptic arch.* It is also sometimes referred to as an *elliptical arch.* Such an arch is shown in Fig. 55. The following is a method of drawing an elliptical arch, also of finding the direction of the joints between the voussoirs.

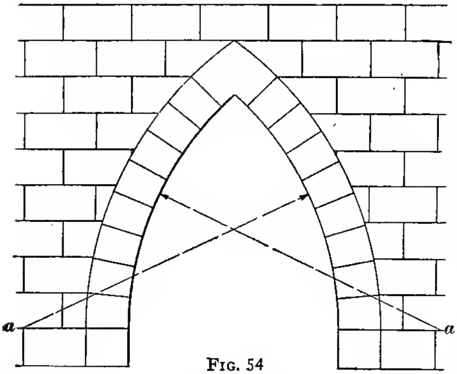


FIG. 54

To draw the intrados: Let *A B* and *C D,* Fig. 55, be the longitudinal and transverse axes of the ellipse. From *C* lay off *C e* and *C f* equal to *A O.* Through *e* and *f* drive two pins or small nails. Tie a piece of string to these two pins of such a length that it will reach to *C* as shown by the dotted line *e C f.*

Now by inserting the point of a pencil inside this string and moving it from *A* to *B,* at the same time keeping the string taut, one-half of the required ellipse will be described. The other half may be similarly described on the opposite side of the longitudinal axis.

The intrados of the arch is then divided off, generally into an odd number of parts of equal size, by the use of the dividers. Through these points the lines of the joints are drawn.

To find the direction of a joint: To find the direction of a joint at any point such as *g*, Fig. 55, draw straight lines from *g* to the foci *e* and *f* of the ellipse. A line *x g Y* bisecting the angle *e g f* will give the direction of the joint.

To bisect the angle: To bisect the angle *e g f*, lay off on the line *g f* a distance *g e′* equal to *g e*. Find the middle point *x* of the line *e e′*. Draw a line through *x* and *g*. This line will bisect the angle.

61. Three-Centered Arches.—A three-centered arch is an arch in which the curve of the intrados consists of the arcs of three different circles. To find the centers of these three arcs, divide the span *a b*, Fig. 56, into three equal parts, *a c*, *c d*, and *d b*. These three parts form the diameters of three circles as shown. Draw the vertical axis *e f* of the arch. This will cut the circumference of the middle circle at *e*. From the point *e* draw lines through *c* and *d*, and extend them indefinitely. With *c* as a center and *c a* as a radius, draw an arc inter-

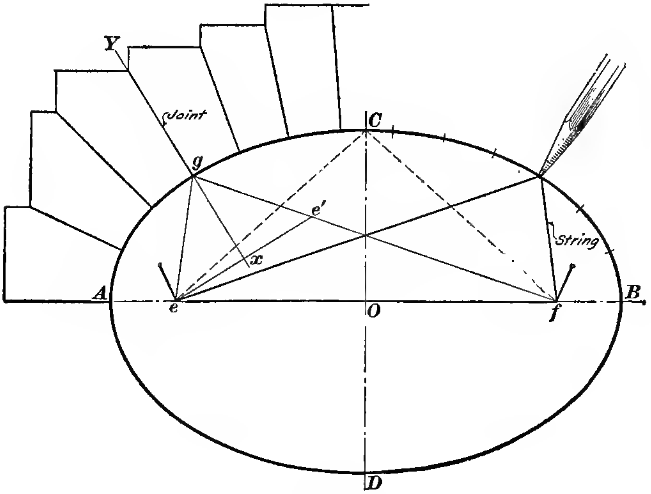


FIG. 55

secting the line through *e c* at *g*. With *d* as a center and *d b* as a radius, draw an arc intersecting the line through *e d* at *h*.

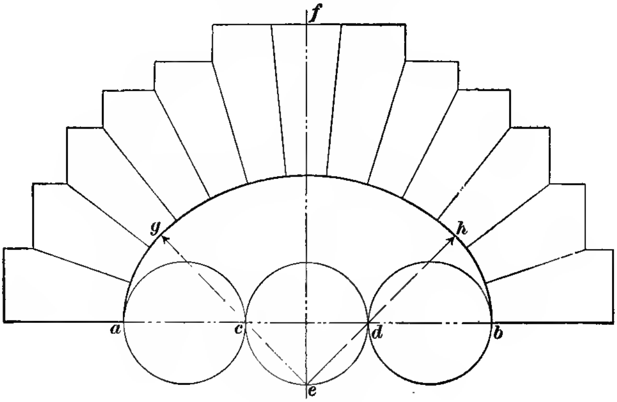


Fig. 56

The portion of the intrados between *g* and *h* is drawn with *e h* or *e g* as a radius and from *e* as a center.

The joints in the central portion are drawn from the center *e*, and the joints between *a* and *g* are drawn from the center *c*. The joints between *b* and *h* are drawn from the center *d*. It will be found in practice that it is much easier to draw an arch of this type than it is to draw an elliptic arch.

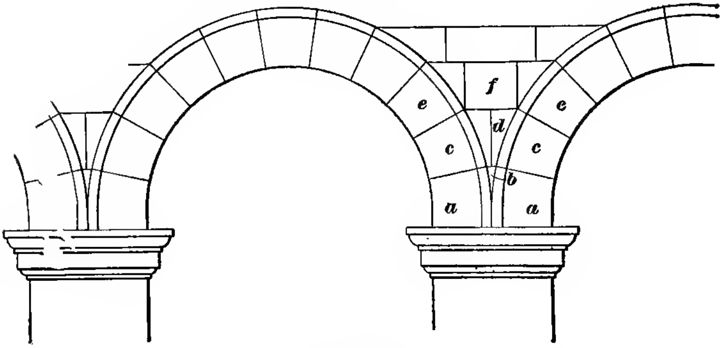


Fig. 57

62. Stilted Arches.—It is found by experience that semicircular arches, when sprung from a horizontal line through the center of the arch, give the effect of the intrados being somewhat less than a semicircle, especially where the piers supporting the arch have large or projecting capitals, as shown in Fig. 57. It is therefore customary to have the center of curvature or center of the arch slightly above the springing line, as shown in Figs. 45 and 57. An arch treated in this manner is called a *stilted arch.* Fig. 53 shows another example of an arch that is stilted. Fig. 50 shows a semicircular arch in which the springing line is *b b*, and the center of curvature *a* is slightly above this line.

63. Construction of Arches.—An arch should be built of the very best kind of ashlar masonry, cut so that the voussoirs bear evenly and closely against one another with thin joints. The joints of the stonework should be of the same thickness throughout, so that bearing may be uniform over the entire surface of the joint. The thickness of the joints depends somewhat on the character of the finish. If the work is finely dressed, $\frac{3}{16}$ inch is the usual thickness, while in rock-faced work it is seldom made less than $\frac{3}{8}$ inch; $\frac{1}{4}$ inch is all that is usually allowed for the best work. Usually, the arch is divided

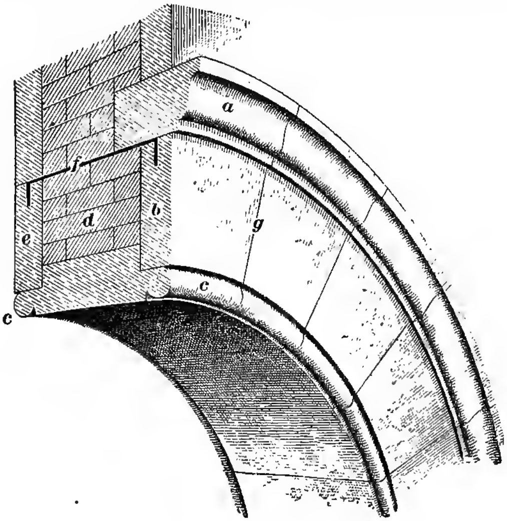


Fig. 58

into an odd number of voussoirs, and in building the arch the keystone is placed in position last.

64. Backing.—As a rule, cut-stone arches in buildings are only from 6 to 8 inches thick, having a backing of brickwork or of a less costly kind of stonework. Large arches, especially when both sides are visible, as in entrances, porches, etc., are often constructed as shown in Fig. 58. In this case, the stone is backed by a brick arch *d*, and these are tied together with clamps *f*, which are fitted into the voussoirs *b* and *e*.

65. Bonding.—Whenever arches are carried on piers or columns, care should be taken in cutting the springers, so that they will bond properly into the masonry. Fig. 57 shows two arches sprung from a pier. The two springers *a* should be made of one piece of stone, so that it will not be necessary to fill up the space *b*, which would require a very small wedge-shaped piece of stone. The voussoirs *c, c* should be separate pieces and should be jointed at *d*. The voussoirs *e, e* would be separated by the stone *f*.

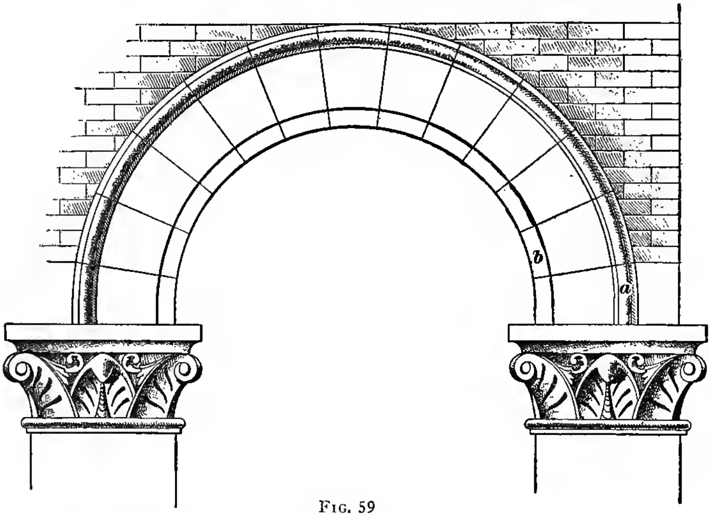


FIG. 59

66. Moldings.—Arches are often decorated by the use of moldings such as shown at *a* and *b* in Fig. 59. These moldings are sometimes cut on the voussoirs, and sometimes they are formed in separate courses, as shown in Fig. 58, which shows the method of constructing the arch shown in Fig. 59. A molding such as shown at *a*, Fig. 58, is generally called a *label molding*. The molding *c* is often referred to as a *soffit molding*.

67. Centers.—In building an arch, it is carried up from both piers, or abutments, at the same time. During construction, the stones must be supported until the arch is completed. For this purpose, as shown in Fig. 60, a framework made of planks cut to exactly fit the curve of the arch is used. This framing, known as a **center,** is supported on posts *g*, and the usual method is to insert wedges *f* between the center framing and the posts supporting it, which, when the arch has been completed and the mortar has set, are driven out gradually, so as to bring the load on the arch without shock. The center

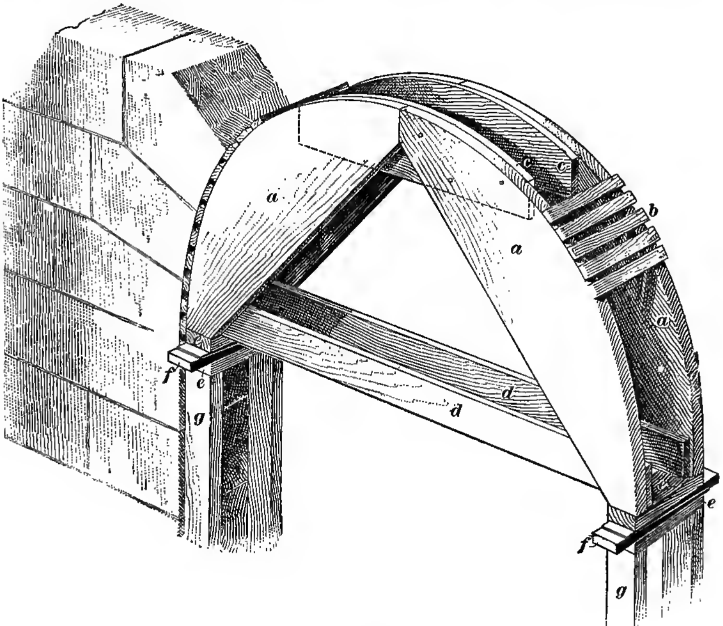


Fig. 60

should be strong enough to support the weight of the arch and a portion of the wall above, as no weight should be put on the arch until the mortar in the joints has become hard.

In Fig. 60 at *a* are shown the *bearers,* which are cut out of 2-inch plank and to a radius about 1 inch less than that of the intrados of the arch. At *c* are indicated pieces of plank, nailed at the crown of the center to splice and stiffen it. Small bearing strips *b,* about 1 in.×2 in. in section and known as *lagging,* are nailed to the curved pieces *a.* At *d* are shown longitudinal braces; at *e,* the plates under the center and on top of the posts; at *f,* the wedges; and at *g,* the posts, which, if quite long, should be braced at the middle.

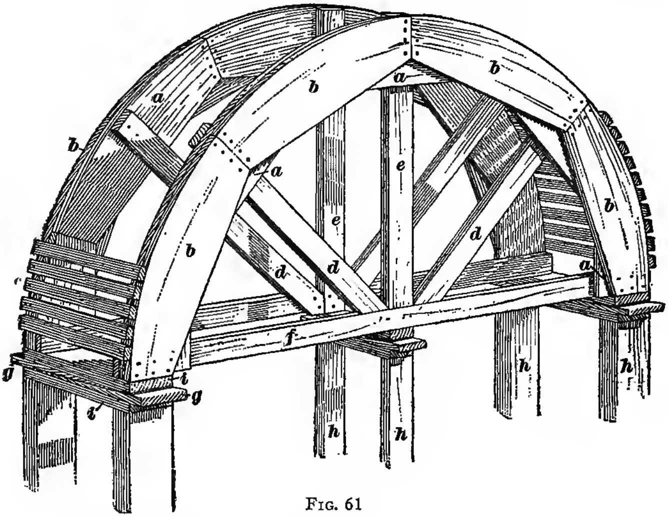


FIG. 61

68. For arches of considerable span, centers more strongly built are necessary. Fig. 61 shows a good form of construction. At *a* and *b* are represented the *bearers,* breaking joint as shown; *c* indicates the *lagging; e,* the uprights; *d,* the inclined braces; *f,* the tie-piece; *i,* the bearing plates, with wedges *g* between; and *h,* the side and center posts. In building large arches, special care should be taken to carry up both sides of the arch equally.

SPECIAL STONES

69. Bond Stones.—Piers that have a horizontal cross-section of less than 9 square feet should be bonded at intervals of from $2\frac{1}{2}$ to 3 feet by having a bond stone built into them. These bond stones should be not less than 4 inches in thickness and should be cut with parallel and level top and bottom beds. They should also extend entirely through the pier. The brick or stone work upon which these stones rest should be brought to a level and the bond stone carefully bedded so as to bear as uniformly as possible upon all parts of the pier. The use of bond stones in constructing piers is required by the building codes of many large cities. Bluestone or granite or other hard stones are best to use for bond stones.

70. Templets, or Bearing Stones.—Where a beam, column, or a specially heavy load, rests upon a small part of a wall, hard stone blocks, called *templets* or *bearing stones*, are usually set under them in order to spread the load over a sufficient amount of surface of the wall below. The loads allowed by building codes are about 15 tons per square foot on brick masonry laid in Portland-cement mortar, and 7 or 8 tons on good rubble masonry laid in Portland-cement mortar. Hence, if a girder or column brings a load of 20 tons on a brick wall, the templet under the end of the girder must be $\frac{20}{15}=1\frac{1}{3}$ square feet in area, or 12 in.×16 in. If the same load is supported on a rubble wall, the size of templet that will be required is $\frac{20}{8}=2\frac{1}{2}$ square feet, or 18 in.×20 in. These templets distribute the load from the narrow flange of the girder over a surface of wall sufficient to support it.

Templets must be cut with parallel beds, must be carefully set so as to have a uniform bearing, and should be of sufficient thickness so that they will not crack under the load. Bluestone, granite, or other hard stones are best to use for templets or bearing stones as these stones are generally subjected to great stresses or loads.

HANDLING AND SETTING STONE

71. Rubble stone is usually obtained from some convenient quarry and is conveyed to the building in wagons or carts. There is no particular care required in handling such stone, as there are no edges or corners that must be protected from injury. Ashlar, or cut stone, however, when cut to a finished shape at the quarry requires considerable care in handling to prevent its being damaged.

SHIPPING AND HANDLING CUT STONE

72. Packing.—Stone being very heavy is expensive to ship, and a decided saving in freight charges can be made by having the stones for a building cut approximately or even accurately to size before shipping. When this is done there is a risk that the finished edges and projecting members on the stones will be broken during shipment. It is therefore customary to protect the edges by strips of wood which are secured by means of metal straps nailed to the strips.

73. Cut stones are frequently conveyed from a local yard to a building in trucks, in which case they are laid upon strips of wood placed on the floor of the truck, and strips of wood are placed between the different stones, so that the stones cannot come in contact with each other. Straw or excelsior is sometimes used instead of wood strips between the stones. Great care must be exercised in placing stones on the truck as well as in removing them, so as not to chip the edges. A stone is practically spoiled if an edge that is intended to appear on the face of the building is spalled or chipped, and such stones are generally condemned by the architect and must be replaced.

Placing stones on and removing them from the truck is best done by means of a derrick, although on small jobs where there may be no derrick the stones are handled by several men who move them about by using metal bars, rollers, etc. There is, however, considerable risk to the stone in this method of handling.

74. Delivery at the Building.—In delivering cut stone at the building it should be placed in a position where it will be protected from harm and should be arranged so that the stones can be reached in the order in which they are to be used. If the stones are to be placed on the ground adjacent to the building, they should have strips of wood placed beneath them so that they will not come into actual contact with the soil, as certain kinds of stone will become stained if they rest directly upon the soil. If they are not placed inside the building they should be carefully covered over with boards until needed in the building.

In city buildings the stones are often hoisted directly upon a wooden bridge that is erected across the sidewalk. Upon this bridge they are trimmed and fitted if necessary before being hoisted into place.

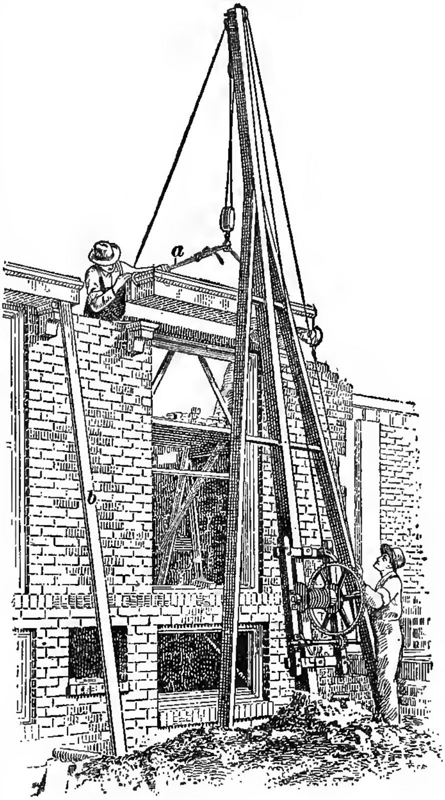


Fig. 62

75. Trimming.—It is often found necessary to refit some of the stones after they have been delivered at buildings. This work is done with hand tools. Sometimes the lewis holes and other holes for attaching the stones to the hoisting apparatus are cut at the building. There is almost always a certain amount of cutting and fitting to be done at a building where much ashlar is used.

76. Raising Stones.—A stone weighing 80 pounds is as heavy as two men can handle successfully on a job. Derricks of some kind are necessary for stones heavier than this. For low buildings where the stones have to be lifted for comparatively short distances a derrick such as shown in Fig. 62 is used, the derrick being supported by a guy rope not shown. One man can raise a stone of considerable weight with this derrick. The illustration shows a stone lintel being set in place. The stone has been raised to a short distance above its final position and is being slowly lowered into place. The man on the ground is operating a brake on the axle of the derrick which permits it to turn around very slowly. The stone is suspended from the ropes on the derrick by means of dogs, or grabs, small holes having been drilled into the ends of the stones and the points of the grabs inserted in them. They are held in place by the tension of the rope *a*.

In tall buildings of steel-frame construction the stones are set with a large boom derrick supported on the top floor of the frame or by smaller derricks attached to the steel columns of the frame. These derricks have booms which can be swung around as well as raised or lowered so as to deliver stones at any point on the front of the building as well as to lift the stone from the ground and raise it into place. These derricks are operated by a hoisting engine located on one of the lower floors of the building. Where only a few stones are to be set, derricks operated by man power may be used.

SETTING STONES

77. General Rules for Stone Setting.—In setting or putting together the stones to form a structure, the following principles or rules must be observed:

1. The vertical joints in any course should not come directly over the vertical joints in the course below.

2. Where the thickness of a wall is made up of two or more pieces of stone, bond stones or blocks that run through from face to face of the wall should be used whenever possible, for the purpose of binding the whole mass together.

3. Where the width of the wall is so great that a long bond stone would be liable to break, headers should be used at frequent intervals, should be placed as nearly over the center of the stretchers as possible, and should extend two-thirds across the wall, alternately from opposite faces.

4. When stratified stones are used, they should be laid on the natural bed; that is, the bed on which they rested in the quarry. Stratified stones when placed vertically are split and scaled by the action of the weather; moreover, a stone in this position has not as much strength to resist crushing as it has when placed with the lamina horizontal. Stones placed with their strata vertical can sustain only six-sevenths of the load borne by similar stones placed on the natural bed. When a stratified stone is used in a cornice with overhanging moldings, however, the natural bed should be placed parallel to the side joints; for, if placed horizontally, layers of the overhanging portions will be liable to drop off. (Precise directions for ascertaining the natural bed of a stone cannot be given. With some stones it is easy to distinguish; with others, it is a matter of extreme difficulty; in case of doubt, the quarry owners should be consulted.)

5. Every joint or space between the stones should be filled with mortar, and the spaces should be as small as possible.

6. The surfaces of porous stones should be moistened with water before being placed in contact with the mortar; otherwise they will absorb the moisture from the mortar, causing the mortar to become a crumbling mass.

7. For the sake of appearance, the largest stones should be placed in the lower courses, the thickness of the courses gradually decreasing toward the top.

8. The rougher the beds and joints, the better the mortar should be. The principal office of the mortar is to equalize the pressure, and the more nearly the stones are dressed to closely fitting surfaces, the less important the quality of the mortar;

with rough beds, the best quality of mortar should be used. This rule is frequently incorrectly reversed; that is, with fine, smooth, dressed beds the best quality of mortar is used. When using stones that have been sawed, it may be necessary to roughen the surface of beds and joints with the point or tooth ax, so that the mortar will adhere.

9. Porous stones should not be placed at or below the ground line.

10. In foundations, absorption of moisture from below should be prevented by placing a course of material that water will not penetrate at or near the surface of the ground.

11. Porous stone should not be employed for copings, cornices, window sills, or other parts of a structure where water is likely to lodge.

12. In setting cut stones, as sills, water-tables, belts, etc., the mortar should be kept back about 1 inch from the face, the space being filled when the pointing is done.

13. If a stone that has once been set requires to be moved for any reason, it should be lifted clear from the mortar bed, the mortar removed, and the stone set in a new bed of mortar in the new position.

14. Hammering or cutting stones on the top of stones just set in the work should not be practiced.

15. All courses that project beyond the general lines of the wall, as sills, lintels, belt-courses, etc., should be covered with boards or otherwise protected from damage.

78. Protection Against Staining.—Certain kinds of stone, such as Indiana limestone, which is used in great quantities, are more or less absorbent, and when brought in contact with cement mortar in the wall are apt to become stained. To avoid this, the backs, joints, and beds of the stones are given one or two coats of some one of the numerous patented waterproofing compounds that are designed to close the pores of the stone and thus prevent water that contains materials that will discolor the stone from working through the stone and appearing on the face. The stones are coated to within about 1½ inches of the face of the stone. These compounds are also designed so that plaster will adhere to them, thus making it possible to apply the plaster directly to the back of the stone without the use of furring and lathing. The adhesion of mortar to this coating is also perfect.

79. Mortar for Ashlar.—The mortar used for setting ashlar when absorbent stones are used should be made of a white non-staining Portland cement and clean white sand, using 1 part of cement to 2 parts of sand. A small proportion of slaked or hydrated lime may be added to the cement and sand to make the mortar work smoothly.

The mortar is sometimes kept back of the face of the wall for a distance of $\frac{3}{4}$ inch so that the front of the joint will be open. This open joint must be pointed up later on. In other cases the joints are flushed full of mortar and are raked out and pointed later on. A good pointing mortar is made of 1 part of white non-staining Portland cement and 1 part white sand, and mortar color if desired. The method of pointing is described in a previous article.

80. Wedges.—The thickness of the joints is important in ashlar and in order that they shall be made of an exact thickness, small wooden wedges are laid in the joints so as to regulate this thickness. These wedges are left in place until the mortar has set, when they may be removed.

81. Use of Pinch Bars.—Pinch bars are small bars of steel, similar to crowbars, with sharpened points, which are used in moving stones, especially ashlar. The use of pinch bars on the joints around the face of the stone should not be allowed, as there is a risk of spalling the stone. Pinch bars may, however, be used at the back and sides of the stones without danger.

82. Leveling, Plumbing, Etc.—The stones should all be set with level beds and plumb joints for straight ashlar, and should be carefully tested before the stone is considered as finally set. The testing is done by the use of a plumb rule and a level.

83. Anchoring, Clamping, and Doweling. **Anchors** are used to fasten ashlar to its backing. All anchors should be of galvanized iron and should receive one or two coats of the same waterproof paint as is used on the backs of the stone. They should extend down into the top of the stone at least $\frac{3}{4}$ inch and up or down into the backing about 2 inches. The holes for the anchors in the stones should be not less than 2 inches in from the face of the stone and should be spaced about 2 feet apart.

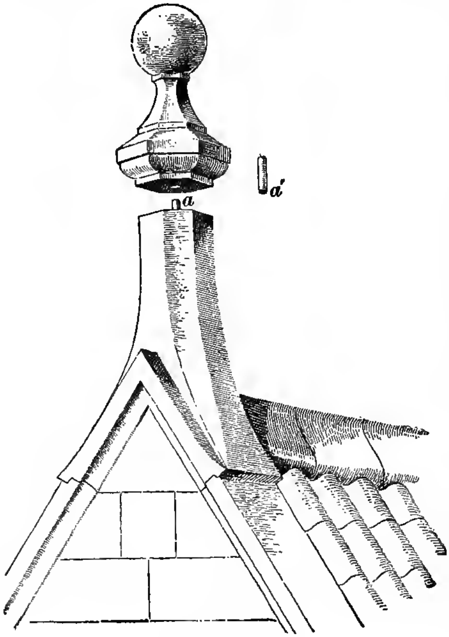


Fig. 63

84. Clamps are used in fastening coping stones together as previously described and shown in Fig. 32. They are let into the tops of adjacent stones, are countersunk, and fastened in place by cement or melted lead.

85. Dowels are pieces of metal bar or of stone let into two adjacent pieces of stone to keep them in alinement or keep them in a fixed position with regard to one another. Fig. 63 shows a finial in which the upper portion is doweled to the lower portion by means of a dowel *a*. This dowel, if of metal, should be of brass or copper, but as these metals are very expensive, galvanized iron is generally used.

A stone dowel is shown in Fig. 32 at *e*, where it joins two sections of coping together. Stone dowels are fastened in the sockets by the use of strong cement mortar.

86. Bracing.—Projecting stones are sometimes held up temporarily by means of wooden braces, as at *a*, Fig. 64. These braces are often necessary until the mortar sets and hardens, to prevent the projecting end of the stone from sagging while the mortar is soft. In Fig. 62 is shown a brace *b*, supporting a window cap until the mortar hardens.

87. Protection From Damage.—As fast as the stonework is set, all window sills, string-courses, and exposed portions of cut stonework that are liable to damage by objects falling upon them should be carefully boxed or covered with boarding securely fastened in position and should be kept covered until the likelihood of damage has passed.

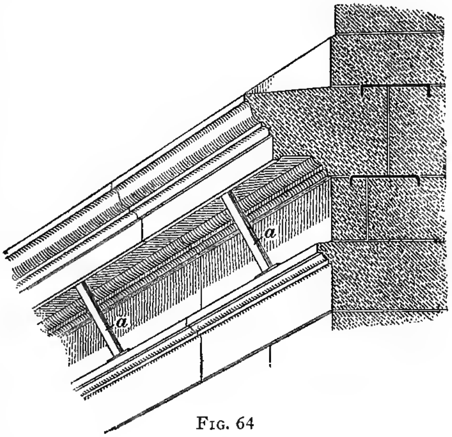


Fig. 64

88. Pointing. The purpose and methods of pointing have already been described. The durability and good appearance of stonework depend largely on proper pointing; therefore, special care should be taken to see that it is well done.

89. Cleaning.—While pointing, it is customary to remove the mortar stains, etc. from the face of the wall. This may be done by scrubbing the stonework with a brush dipped in water containing muriatic acid, the proportions being about 20 parts of water to 1 part of acid. For cleaning granite and hard limestone, wire brushes are used, and for sandstones and other soft stones, stiff bristle brushes usually serve the purpose. The stonework should be scrubbed until all mortar stains are removed.

The sand blast, worked by either steam or compressed air, does the work of cleaning walls very effectively and rapidly; it removes the outer layer of the discolored stone, and leaves a fresh, bright surface. Even fine carvings have been very successfully cleaned by this method.

STRENGTH, MEASUREMENT, AND INSPECTION OF STONEWORK

STRENGTH OF STONE MASONRY

90. The strength of stone masonry depends upon the shapes of the stones used, the manner in which they are laid,

TABLE I

SAFE LOADS ON STONE MASONRY ACCORDING TO LAWS OF DIFFERENT CITIES

Kind of Masonry	Kind of Mortar	Boston	New York	Chicago	Denver	Seattle	Davenport
		Load, Pounds per Square Inch					
Rubble, Ordinary ...	Portland Cement	...	140	100	167	100	140
Rubble, Ordinary ...	Lime and Cement	...	100	...	...	...	100
Rubble, Ordinary ...	Lime	...	...	60	56	60	70
Rubble, Coursed	Portland Cement	...	...	200	...	200	...
Rubble, Coursed	Lime	...	...	120	...	120	...
Granite—Ashlar	Portland Cement	834	600	600	556	...	600
Limestone—Ashlar ..	Portland Cement	556	600	...	...	...	600
Sandstone—Ashlar ..	Portland Cement	417	300	400	167	...	300

and upon the quality of the mortar used. Thus, ordinary rubble masonry composed of irregular-shaped stones, in which the spaces between the larger stones are filled with spalls and lime mortar, is very weak when compared with a wall built of the same stone finely cut, carefully bonded, and laid up in Portland-cement mortar.

Table I gives the loads per square inch that are allowed on masonry of various kinds by the building laws of several cities in the United States. These loads represent good practice and must be observed by architects and contractors working in those cities.

TABLE II

SAFE LOADS ON STONE COLUMNS

Kind of Stone	Load per Square Foot Tons
Sandstones—	
Potsdam, New York, best	40
Longmeadow, Massachusetts, best	35
Manitou, Colorado, best	25 to 30
Ohio	25
Fond du Lac, Wisconsin	25
Limestones—	
Glens Falls, New York	35
Indiana	25 to 35
Marble—	
Good quality	40

The loads given for granite, limestone, and sandstone ashlar are for walls built of carefully squared blocks of stone set in Portland cement and well bonded together.

91. Strength of Stone Columns.—A column of good stone that is carefully set and has well-dressed bearing surfaces should, if its height is not over ten times its diameter, safely carry a load about one-fifteenth of the crushing load of stone of the same quality. Table II gives the safe bearing values for different kinds of stone columns when the shaft consists of a single piece.

MEASUREMENT OF STONEWORK

92. Dimension Stone and Rubble.—At the quarry, stone is divided into two classes: *dimension stone* and *rubble*. **Dimension stone** consists of those pieces that are quarried in regular shapes, and to a fixed size; they are usually 4 square feet or more in area and over 8 inches thick. This class of stone is usually sold by the cubic foot, and costs about three or four times as much as rubble. In some cases rubble is the only product of the quarry and in others it is a secondary product to the dimension stone.

Rubble includes pieces of various sizes and shapes. It is suitable for work in which the courses are 12 inches or less in height and the stones are not over 24 inches long. Generally speaking, all stone not quarried to a certain size may be termed rubble. Rubble stone is usually sold by the carload, or in small quantities by the perch, and in some localities by the ton.

93. Measuring Methods.—Footings built of dimension stone are generally measured by the square foot. If built of large rubble, or irregular stones, the footings are usually figured in with the walls, with allowance for the extra width. Rubble is usually measured by the perch, which varies from 16 to 25 cubic feet, being 24¾ cubic feet in the Eastern States, 16⅔ cubic feet, by custom, in Colorado, and 22 to 25 cubic feet in various other places. A necessary precaution when work is to be measured by the perch is to agree on the number of cubic feet in a perch, and also in regard to deductions for openings. If this is not done, the custom of the particular locality will probably govern in case of disagreement. In some places, rubble work is measured by the cubic yard of 27 cubic feet or by the cord of 128 cubic feet. Stone backing is commonly figured the same as rubble. In measuring rubble walls for estimating, the corners are counted twice so that the extra labor of plumbing and cutting them will be provided for. In other words, the length of the wall is measured to the extreme edge of the wall on both sides.

94. Ashlar masonry is almost invariably measured by the square foot, the cost depending on the kind of work and the size of the stones. It is usual to deduct openings in ashlar work; when the width of the jambs of windows is more than the depth of the ashlar, the jambs are usually measured in with the facework. Flagging and all thin pieces or slabs are also figured by the square foot.

Moldings, belt-courses, and cornices are usually measured by the linear foot, but if the shapes are not regular they are figured by the cubic foot. All carved work is estimated by the piece.

Trimmings are sometimes figured by the cubic foot, the price varying with the amount of labor required in dressing. Probably the most accurate way of figuring this class of work is first to estimate the value of the rough stone and then that of the labor involved in the different classes of work, the resulting prices being per linear foot. This method is the one usually employed in figuring granite work

---

INSPECTION

95. The inspector or superintendent should be very careful to have the work properly done during erection—both the cutting and the setting of the stone—for if an imperfect piece is once set in place it cannot be removed without considerable trouble. The stones must also be carefully examined, as otherwise many cracked and defective ones may be used, either by accident or design.

96. **Stone Defects.**—Granite may contain cracks, black or white lumps known as *knots,* and a brownish stain called *sap.* When such defects are found, the stone should be rejected, if the importance of the work justifies it. Cracks are the main things to guard against, however, and they may be detected by the absence of the clear ringing sound when the stone is struck with a hammer.

Sand holes are frequently found in sandstones. These are bodies of uncemented sand that become dislodged by jarring or by the action of water and produce a pitted appearance and an uneven color. Attention must also be paid to securing uniformity of color, as sandstone from different parts of the same quarry may vary greatly in this respect.

97. Patching.—**Patching** is often resorted to when a piece has been broken from a stone. Instead of using a new stone, the old one is patched by gluing on the spall with shellac, the joint being hidden by rubbing stone dust over it. Rain, however, will wash out the shellac. There are times when a patch is allowable, as, for example, when a new stone cannot be had without great expense and delay. In such a case, the superintendent may permit patching to be done, but care should be taken to put on the spall by inserting it, when possible, in a square hole, or dovetailing it in such a way that it will not become displaced.

98. Faults in Dressing Stone.—The common faults of cut stone are coarseness and poor workmanship. Frequently, the ends of cornices, belt-courses, etc. will not properly match. It should be strictly required that the utmost care be taken in cutting all similar pieces to the same pattern, and that the abutting surfaces be closely dressed. In case these courses do not match they should be cut so as to remedy this defect after they are set in place.

99. Laying Stonework.—In erecting stonework, care should be exercised to have the stone set on the natural bed, with good joints, and not in too small nor in too thin pieces. The bed joints in ashlar work should be perpendicular to the face of the wall, and not less than 4 inches wide at both top and bottom. The proper bonding of the walls should be given very careful attention, as well as the placing of lintels, copings, wall anchors, etc.

Another point that requires attention is the formation of the joints on which great pressure comes; the mortar should be kept back from the face, so that the edges of the stones will not be chipped off.

CONCRETE CONSTRUCTION

MATERIALS AND METHODS

GENERAL EXPLANATIONS

1. Concrete is a mixture of cement, water, and sand, with broken stone, gravel, or cinders. When thoroughly mixed in the proper proportions and allowed to stand for a few days it becomes a hard rock-like material.

When freshly mixed it can be poured into molds or forms and will harden and take the shape of the molds. Hence, walls, columns, girders, and beams can be made by pouring concrete into properly shaped forms and allowing the concrete to harden, after which the forms may be removed.

2. Cement is a finely ground powder that will remain inactive while kept dry, but which, when mixed with water and allowed to stand for a short time, forms a hard stone-like mass.

Cement when mixed with sand and water in proper proportions forms a mortar. The cement, in hardening, binds together the particles of sand and forms a hard substance. The cement also adheres to bricks and stones between which mortar is laid, thus binding them together to make a solid wall.

3. If pieces of stone, gravel, slag, or cinders are mixed with mortar, **concrete** is formed. Its strength and usefulness depend upon the strength and proportions of the various ingredients used. In both mortar and concrete, the greater the proportion of cement that is used (within the limits of the

COPYRIGHTED BY INTERNATIONAL TEXTBOOK COMPANY. ALL RIGHTS RESERVED

proportions commonly used in mortar), the stronger the resulting product will be.

4. Aggregates.—The stone, gravel, slag, and cinders entering into the composition of concrete are called *aggregates,* or *coarse aggregates.* Sand is also considered as an aggregate and is referred to as a *fine aggregate.*

5. Mixing.—The process of mixing concrete is a mechanical one and can be done by hand labor or somewhat more efficiently by machines called mixers. The process of mixing will be described later.

CEMENT

6. Description of Cement.—The cement here referred to is *Portland hydraulic cement.* It is manufactured by mixing together limestone and clay, grinding them to a powder; burning at a high temperature in a kiln; and grinding the resulting clinkers into an impalpable powder. Cement and its properties are described in the Section *Limes, Cements, and Mortars.*

7. Forms of Package.—Cement is sometimes sold in barrels, but is more generally sold in bags, as the bags are smaller than barrels and are consequently more easily handled. A bag contains about 94 lbs. and in practice is counted as 1 cu. ft. in volume. A barrel contains the equivalent of 4 bags.

8. Storing of Cement.—When cement is received on a job it should be carefully stored in a suitable shed or house until used. Such a shed should be constructed with a floor raised above the ground and formed of two thicknesses of flooring boards with a layer of waterproof paper between them. The walls and roof should also be made waterproof.

The bags of cement should be stored in the shed so that there will be a free circulation of air that will prevent dampness. The bags belonging to each shipment of cement should be piled separately so that their identity shall not be lost.

9. Testing of Cement.—It is customary for manufacturers to test the cement in each of their storage bins, and the results of the tests of the cement from the bin from which shipment is made can be obtained by the contractor or architect if he so desires.

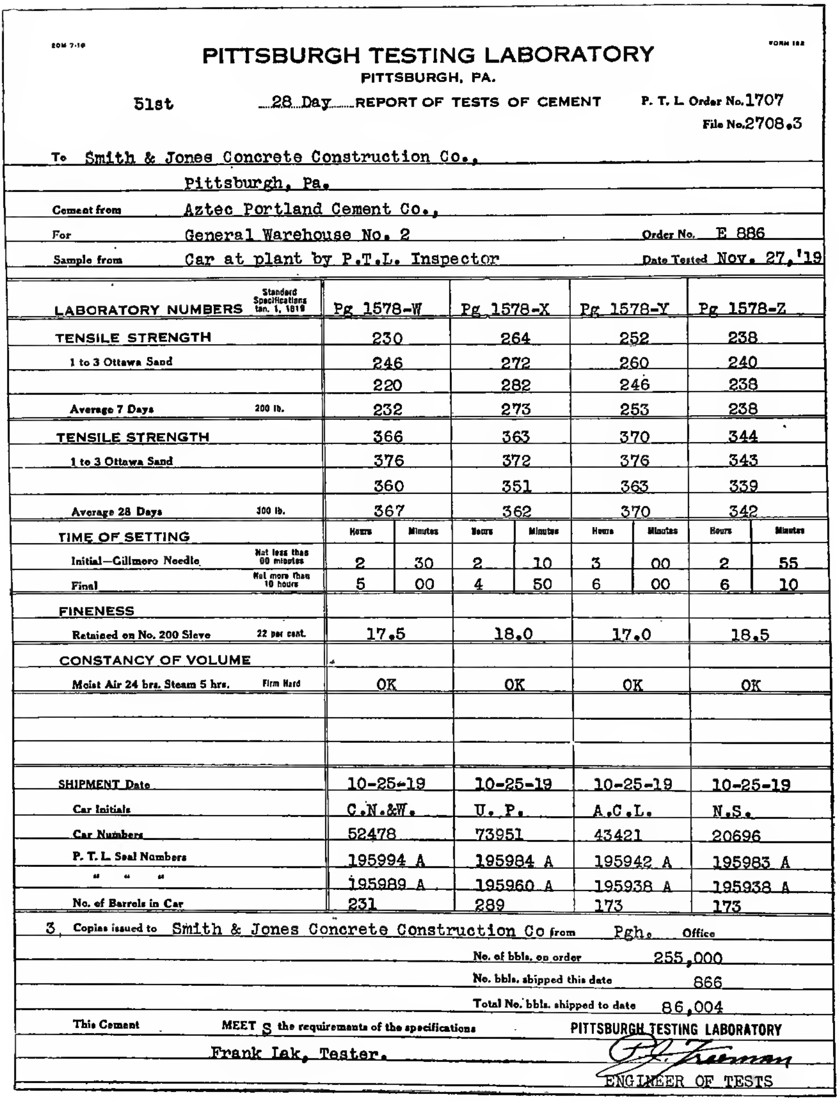
It is advisable, however, especially where the work in which the cement is to be used is large or important, to test the cement as it arrives at the building. This testing is best done by firms that make a practice of doing such work, who have special testing laboratories, and are generally found in all large cities.

10. When such a firm is engaged to test the cement for a building it sends a representative to the car or place where the cement is delivered and the representative secures samples of the cement in every shipment, marks the packages for identification and, if the shipments are to remain on the railroad car until examined, seals the car. The samples are taken to the laboratory, tests are made and the results compared with the standard requirements for cement as laid down by the American Society for Testing Materials. The results of the tests are formulated in reports which show the results in comparison with the standard requirements.

11. Laboratory Report.—A sample laboratory report is shown in Fig. 1. This report is made by the Pittsburgh Testing Laboratory, of Pittsburgh, Pa., on cement that was shipped for use in the construction of a General Warehouse No. 2, and was delivered at the site in railroad cars.

The report shows the results of a 7-day test and a 28-day test. The 7-day test had been previously reported but is incorporated in this report.

12. In the first vertical column are shown in larger type the required tests. At the right of the heading Laboratory Numbers is printed in smaller type Standard Specifications, Jan. 1, 1919. This indicates the date of the latest specifications prepared by the American Society for Testing Materials. Below this are the standard requirements as they relate to the different tests. The marks Pg 1578-W, Pg 1578-X, etc. at the tops of the second, third, fourth, and fifth columns are the



20M 7-19 FORM 182

PITTSBURGH TESTING LABORATORY

PITTSBURGH, PA.

51st ..28 Day.... REPORT OF TESTS OF CEMENT P. T. L. Order No. 1707

File No. 2708.3

To Smith & Jones Concrete Construction Co.,
Pittsburgh, Pa.

Cement from Aztec Portland Cement Co.,

For General Warehouse No. 2 Order No. E 886

Sample from Car at plant by P.T.L. Inspector Date Tested Nov. 27, '19

LABORATORY NUMBERS	Standard Specifications Jan. 1, 1919	Pg 1578-W		Pg 1578-X		Pg 1578-Y		Pg 1578-Z	
TENSILE STRENGTH		230		264		252		238	
1 to 3 Ottawa Sand		246		272		260		240	
		220		282		246		238	
Average 7 Days	200 lb.	232		273		253		238	
TENSILE STRENGTH		366		363		370		344	
1 to 3 Ottawa Sand		376		372		376		343	
		360		351		363		339	
Average 28 Days	300 lb.	367		362		370		342	
TIME OF SETTING		Hours	Minutes	Hours	Minutes	Hours	Minutes	Hours	Minutes
Initial—Gillmore Needle	Not less than 60 minutes	2	30	2	10	3	00	2	55
Final	Not more than 10 hours	5	00	4	50	6	00	6	10
FINENESS									
Retained on No. 200 Sieve	22 per cent.	17.5		18.0		17.0		18.5	
CONSTANCY OF VOLUME									
Moist Air 24 hrs. Steam 5 hrs.	Firm Hard	OK		OK		OK		OK	

SHIPMENT Date	10-25-19	10-25-19	10-25-19	10-25-19
Car Initials	C.N.&W.	U. P.	A.C.L.	N.S.
Car Numbers	52478	73951	43421	20696
P. T. L. Seal Numbers	195994 A	195984 A	195942 A	195983 A
" " "	195989 A	195960 A	195938 A	195938 A
No. of Barrels in Car	231	289	173	173

3, Copies issued to Smith & Jones Concrete Construction Co from Pgh. Office

No. of bbls. on order 255,000

No. bbls. shipped this date 866

Total No. bbls. shipped to date 86,004

This Cement MEET S the requirements of the specifications PITTSBURGH TESTING LABORATORY

Frank Lak, Tester.

P. J. Freeman
ENGINEER OF TESTS

FIG. 1

laboratory marks used to identify the samples of cement taken from the different cars. Samples are taken from a number of packages in each car and a sufficient amount of cement is taken so that several tests can be made.

13. In the second, third, fourth, and fifth columns at the bottom of the report are given the dates of shipment, the initials and numbers of the railroad cars, the Pittsburgh Testing Laboratory's seal numbers, and the number of barrels of cement in each car.

The seal numbers are the numbers on the seals that are placed on the two doors of each car after the laboratory inspector has taken his samples. If these seals are broken or missing the testing company will not guarantee that the cement in the cars is the same as that they have tested.

14. Under the headings Tensile Strength, the note "1 to 3 Ottawa Sand" signifies that the samples of cement were mixed with Ottawa sand, in proportions of one part of cement to three parts of sand. The Ottawa sand is obtained in Ottawa, Ill., and is accepted as a standard so as to insure uniformity in preparing samples for testing purposes. The sand is selected so that its particles will pass through a sieve having 20 meshes to the linear inch or 400 openings to the square inch and will not pass through a sieve having 30 meshes to the linear inch or 900 openings to the square inch.

The results of the tests for tensile strength are given for samples that have hardened or set for 7 days. In the second column are shown the results of tests of three samples marked Pg 1578-W. These results are 230, 246, and 220. These are the strengths, in pounds per square inch, of the samples tested. The fourth figure, 232, is the average strength of the three samples. The requirements of the standard specifications are 200 pounds per square inch. These tests are therefore satisfactory.

The tests of the 28-day-old specimens show an average strength of 367 pounds, whereas the standard specifications call for only 300 pounds. This test is also satisfactory.

15. The standard specifications require that the cement shall gain its initial set in not less than 60 minutes and its final set in not more than 10 hours. By noting the results given for the various samples they will be seen to have passed this test satisfactorily. The Gillmore needle is a laboratory device for testing cement and will not be described here.

16. The fineness of cement is measured by sieves. The standard specification requires that not more than 22 per cent. of the cement be retained on a sieve having 200 meshes to the linear inch or 40,000 meshes to the square inch. All the samples have passed through the standard sieve leaving less than 22 per cent. on the sieve and are sufficiently fine.

17. In the constancy of volume test it is required that after a specimen has been mixed with water and exposed to moist air for 24 hours and steam for 5 hours it shall be firm and hard. The O. K. in the report indicates that the samples have met this test successfully.

The report shows that the cement in the shipment has successfully met the requirements of the Standard Specifications and this is testified to by the signatures of the tester and the engineer of tests. This is accepted by the architect as evidence that the cement is satisfactory.

AGGREGATES

18. Kinds of Aggregates.—The materials most commonly used as aggregates are sand, stone, gravel, and slag. Sand and gravel are usually obtained from natural deposits, while the rock aggregate is obtained by crushing masses of rock that are too large to be used in the concrete.

These materials must be screened or graded. By grading is meant separating the particles into various sizes. These various sizes are mixed together again, when mixing the concrete, the proper proportions of the different sizes being used so as to make the most compact mixture.

When the particles of stone are $\frac{1}{4}$ inch or less in size they are considered as sand.

19. Sand.—It is usually required that sand for concrete shall be sharp, coarse, and clean. It is not, however, so essential that the sand be sharp but it must be clean and consist of particles most of which are coarse, or about $\frac{1}{4}$ inch in diameter. Sand is clean when it is free from foreign substances such as clay, loam, and vegetable matter. Clay and loam can be removed from the sand by washing. Sand containing vegetable matter should not be used.

If there is any doubt about the suitability of a given sand it can be examined at the testing laboratories, where specimens of the proposed sand mixed with cement and standard sand mixed with cement can be tested and compared. Good building sand will give as great, and in most cases greater, strength than Ottawa sand.

20. Stone.—It is also important that the stone be clean and of the proper size and kind. If the stones are mixed with dirt or other foreign substances they can be washed. The stone, as well as the sand, should be kept clean in suitable wooden bins from which it may be taken as needed. On small jobs, however, this may be too expensive, and a wooden platform laid on the ground may be used instead.

21. Maximum Size of Stone Aggregates.—It is very important that stones of the proper size be used. The sizes of most of the stones used in concrete should be as large as possible consistent with the character of the work. These should be mixed with a proper selection of smaller stones, to fill in the voids. For large masses of concrete, stones as large as two or three inches in their greatest diameter may be used; for reinforced concrete, stones one inch in diameter are as large as can conveniently be used. For concrete blocks, very small stones are sometimes used, but sometimes they are omitted, as the blocks are generally made hollow and with thin shells and webs that are not thick enough to accommodate large pieces of aggregate.

When the dimensions of the concrete work are very large, stones of considerable size are often bedded in the concrete with the object of saving cement, sand, and labor in mixing concrete. In architectural work, however, concrete work of large dimensions is not often employed, and such stones are rarely used.

22. Value of Different Kinds of Stone.—The relative value of different kinds of stone for aggregates is about as follows: Trap, granite, gravel, sandstone, hard limestone, and soft limestone. Other materials that may be used as aggregates are slag, shale, slate, and cinders.

23. The most effective stone to use as an aggregate is *trap rock,* which is a rock of igneous origin. This stone is very tough and strong. *Granites* are also strong and suitable, as they are very hard and durable. *Limestones* of the harder kinds are also satisfactory, as are also the harder kinds of *sandstones. Slate* and *shale,* unless of very solid and durable character, should be used only when no better material can be obtained, as they are subject to disintegration.

24. Slag of certain kinds makes an excellent aggregate and has the advantage of being lighter than stone and consequently making a concrete that is light in weight and at the same time as strong as some of the stone concretes.

25. Cinders are comparatively light in weight and are useful in making concrete for fireproofing purposes. Cinder concrete will add less to the weight of a structure than stone concrete.

PROPORTIONING OF INGREDIENTS

PROPER PROPORTIONS

26. Proportioning of Mortar.—Since in forming mortar the cement acts as a binder between the grains of sand, there must be enough cement in the mortar to coat completely each grain of sand with cement and to fill the spaces, called *voids,* between the grains. The amount of cement actually used must, therefore, be sufficient both to coat the grains and to fill the voids. It follows that the smaller the voids, the less cement will be needed; and since the cement is the expensive ingredient of the concrete, it is most economical to use sand having few voids. Such a sand is one consisting of particles of many sizes, from coarse to fine, but with the coarse particles predominating.

27. With sand having the properties just described, a very strong and dense mortar can be obtained by mixing one part of cement to two parts of sand. This mixture is called a 1 : 2 mortar and is a mixture very frequently used. Where greater strength is required, the amount of sand used may be reduced, and a 1 : 1 or 1 : 1½ mixture used. Where the strength is not very important, the sand ingredient may be increased to three parts for each part of cement, making the mortar a 1 : 3 mixture. Mortar concrete containing a large proportion of cement is called *rich;* that with a small proportion of cement is called *lean.*

28. Measuring by Volume.—The various ingredients that enter into the making of mortar and concrete are measured by volume. In practice, when it is desired to make mortar, the cement is measured by taking one or more bags of cement, each of which counts as 1 cubic foot, and one or more cubic feet of sand. If the cement has been shipped in barrels, the ratio is determined in a similar manner, the barrel containing an equivalent of four bags of cement, or 4 cubic feet. The sand is usually measured in wheelbarrows, the cubical contents of the wheelbarrow having been previously determined by a test. If a 1 : 2 mixture is desired, a wheelbarrow which will hold 2 cubic feet is filled with sand and this sand and one bag of cement would be mixed together. The amount mixed at any one time is called a **batch.** A batch is called a one-bag batch if only one bag of cement is used, or a two-bag batch if two bags are used, and so forth. How the mixing is actually done will be described presently in connection with concrete.

29. Proportioning Concrete. — The mortar which serves as a binder between the coarse aggregates in the concrete, must be sufficient in quantity not only to coat each stone, but

TABLE I

QUANTITIES OF INGREDIENTS FOR CONCRETE OF VARIOUS PROPORTIONS

Proportion of Ingredients			Ingredients Required for 1 Cubic Yard of Rammed Concrete											
			Stone, 1 Inch and Under—Dust Screened Out			Stone, 2½ Inches and Under—Dust Screened Out			Stone, 2½ Inches—With Most Small Stone Screened Out			Gravel, ¾ Inch and Under		
Cement	Sand	Stone	Cement Barrels	Sand Cubic Yard	Stone Cubic Yard	Cement Barrels	Sand Cubic Yard	Stone Cubic Yards	Cement Barrels	Sand Cubic Yard	Stone Cubic Yards	Cement Barrels	Sand Cubic Yard	Gravel Cubic Yard
1	1.0	2.0	2.57	.39	.78	2.63	.40	.80	2.72	.41	.83	2.30	.35	.74
1	1.0	2.5	2.29	.35	.88	2.34	.36	.89	2.41	.37	.92	2.10	.32	.80
1	1.0	3.0	2.06	.31	.94	2.10	.32	.96	2.16	.33	.98	1.89	.29	.86
1	1.0	3.5	1.84	.28	.98	1.88	.29	1.00	1.88	.29	1.05	1.71	.26	.91
1	1.5	2.5	2.05	.47	.78	2.09	.48	.80	2.16	.49	.82	1.83	.42	.73
1	1.5	3.0	1.85	.42	.84	1.90	.43	.87	1.96	.45	.89	1.71	.39	.78
1	1.5	3.5	1.72	.39	.91	1.74	.40	.93	1.79	.41	.96	1.57	.36	.83
1	1.5	4.0	1.57	.36	.96	1.61	.37	.98	1.64	.38	1.00	1.46	.33	.88
1	1.5	4.5	1.43	.33	.98	1.46	.33	1.00	1.51	.35	1.06	1.34	.31	.91
1	2.0	3.0	1.70	.52	.77	1.73	.53	.79	1.78	.54	.81	1.54	.47	.73
1	2.0	3.5	1.57	.48	.83	1.61	.49	.85	1.66	.50	.88	1.44	.44	.77
1	2.0	4.0	1.46	.44	.89	1.48	.45	.90	1.53	.47	.93	1.34	.41	.81
1	2.0	4.5	1.36	.42	.93	1.38	.42	.95	1.43	.43	.98	1.26	.38	.86
1	2.0	5.0	1.27	.39	.97	1.29	.39	.98	1.33	.39	1.03	1.17	.36	.89
1	2.5	3.5	1.45	.55	.77	1.48	.56	.79	1.51	.58	.81	1.32	.50	70

1	2.5	4.0	1.35	.52	.82	1.38	.53	.84	1.42	.54	.87	1.24	.47	.75
1	2.5	4.5	1.27	.48	.87	1.29	.49	.88	1.33	.51	.91	1.16	.44	.80
1	2.5	5.0	1.19	.46	.91	1.21	.46	.92	1.26	.48	.96	1.10	.42	.83
1	2.5	5.5	1.13	.43	.94	1.15	.44	.96	1.18	.44	.99	1.03	.39	.86
1	2.5	6.0	1.07	.41	.97	1.07	.41	.98	1.10	.41	1.03	.98	.37	.89
1	3.0	4.0	1.26	.58	.77	1.28	.58	.78	1.32	.60	.80	1.15	.52	.72
1	3.0	4.5	1.18	.54	.81	1.20	.55	.82	1.24	.57	.85	1.09	.50	.75
1	3.0	5.0	1.11	.51	.85	1.14	.52	.87	1.17	.54	.89	1.03	.47	.78
1	3.0	5.5	1.06	.48	.89	1.07	.49	.90	1.11	.51	.93	.97	.44	.81
1	3.0	6.0	1.01	46	.92	1.02	.47	.93	1.06	.48	.97	.92	.42	.84
1	3.0	6.5	.96	.44	.95	.98	.44	.96	1.00	.45	1.01	.88	.40	.87
1	3.0	7.0	.91	.42	.97	.92	.42	.98	.94	.42	1.05	.84	.38	.89
1	3.5	5.0	1.05	.56	.80	1.07	.57	.82	1.11	.59	.85	.96	.50	.76
1	3.5	5.5	1.00	.53	.84	1.02	.54	.85	1.06	.56	.89	.92	.48	.78
1	3.5	6.0	.95	.50	.87	.97	.51	.89	1.00	.53	.92	.88	.46	.80
1	3.5	6.5	.92	.49	.91	.93	.49	.92	.96	.51	.95	.83	.44	.82
1	3.5	7.0	.87	.47	.93	.89	.47	.95	.91	.49	.98	.80	.43	.85
1	3.5	7.5	.84	.45	.96	.86	.45	.98	.86	.47	1.01	.76	.41	.87
1	3.5	8.0	.80	.42	.97	.82	.43	1.01	.81	.45	1.04	.73	.39	.89
1	4.0	6.0	.90	.55	.82	.92	.56	.84	.95	.58	.87	.83	.51	.77
1	4.0	6.5	.87	.53	.85	.88	.53	.87	.91	.55	.90	.80	.49	.79
1	4.0	7.0	.83	.51	.89	.84	.51	.90	.87	.53	.93	.77	.47	.81
1	4.0	7.5	.80	.49	.91	.81	.50	.93	.84	.51	.96	.73	.44	.83
1	4.0	8.0	.77	.47	.93	.78	.48	.95	.81	.49	.98	.71	.43	.86
1	4.0	8.5	.74	.45	.95	.76	.46	.98	.78	.47	1.01	.68	.42	.88
1	4.0	9.0	.71	.43	.97	.73	.44	1.01	.75	.45	1.04	.65	.40	.89
1	5.0	9.0	.66	.50	.90	.67	.52	.93	.70	.53	.96	.61	.46	.83
1	5.0	10.0	.62	.47	.95	.63	.48	.96	.65	.50	1.00	.57	.43	.87

also to fill the voids between the stones. The voids between the stones are smallest when the stones are not all of the same size but vary from the coarsest down to the ¼-inch size. For such stones a commonly used mixture is one part of cement, two parts of sand, and four parts of stone, commonly written 1 : 2 : 4; but richer mixtures, such as 1 : 1½ : 3, are occasionally used for very thin reinforced-concrete sections and columns, also for certain kinds of concrete pavements. Leaner mixtures, such as 1 : 2½ : 5, are frequently used in architectural work for basement walls and the like. The mixture 1 : 3 : 6 is about as lean as concrete should be mixed. This mixture may be used for heavy walls, also for cellar floors where it is intended to cover the concrete with a wearing surface of some kind, such as a wooden floor or a cement finishing coat. It is also used in making cinder concrete that is used to fill in over slabs of concrete which are used in fireproof floors.

30. Quantities of Materials Required for Concrete. Concrete is usually measured by the cubic yard, and tables giving the quantities of materials are usually based upon the cubic yard as a unit. There are 27 cubic feet in a cubic yard.

The amounts of cement, sand, and stone required to make up 1 cubic yard of concrete vary with the mixture, a richer concrete requiring more cement per cubic yard than a lean concrete. The quantities also vary according to whether the aggregates are well graded in size or not.

31. Table I.—Table I gives the quantities of ingredients that will be required to make 1 cubic yard of rammed concrete, or concrete that is tamped or rammed into its position, when the ingredients are used in different proportions. It is assumed that materials of average quality are used such as will customarily be employed in actual practice. The following example will illustrate the use of this table:

Example.—What quantities of the various ingredients will be required to make 20 cubic yards of 1 : 2 : 4 stone concrete, using stone 1 inch and under in diameter with the dust screened out?

Solution.—In Table I it will be seen that for a 1 : 2 : 4 mixture, using 1-inch stone and under with dust screened out, 1.46 bbl. of cement,

.44 cu. yd. of sand, and .89 cu. yd. of stone will be required to make 1 cu. yd. of concrete. For 20 cu. yd. of concrete the following will be required:

$$\left.\begin{array}{l}20\times 1.46=29.20 \text{ bbl., or 117 bags of cement}\\ 20\times .44=\ 8.80 \text{ cu. yd. or 9 cu. yd. of sand}\\ 20\times .89=17.80 \text{ cu. yd. or 18 cu. yd. of stone}\end{array}\right\}\text{Ans.}$$

When estimating the quantities required for a given job, an allowance of about 5 per cent. additional should be made for waste.

32. Amount of Water Required.—The amount of water required in concrete varies greatly, because the concrete may be mixed wetter or drier, and also because the materials may absorb a smaller or a greater quantity of water. The proportion of cement used also has a great influence upon the amount of water used. However, as a rough approximation, it may be stated that it takes one gallon of water to each cubic foot of the solid ingredients used in the batch.

33. Consistency of Concrete.—Concrete mixtures are usually classed as *dry, medium,* or *wet,* according to the amount of water used in them. The concrete generally used for construction work is a medium mixture, which produces a concrete of such consistency that it will flow sluggishly into the forms without separation of the materials. If less water is used, the mixture becomes so stiff that it cannot be properly placed in the forms. If more water be used, the aggregates settle in the mass and cause pockets of water to be formed which produce voids in the finished concrete or a soft chalk-like product is formed that has no strength.

If too much or too little water is used, there is a loss of density and strength as compared with concrete of the proper consistency.

MIXING OF CONCRETE

34. Methods of Mixing Concrete.—There are two methods of mixing concrete, namely, by hand and by machine. Concrete is mixed by hand where only small quantities are required and where a machine is not available. Machine-mixed concrete is greatly to be preferred because the ingredients are more uniformly mixed, and the concrete is turned out more rapidly and usually at less cost for labor.

The quantity of concrete mixed in one operation is called a *batch.* The mixing operation comprises the measuring of the several materials required for the batch, the conveying of the materials to the place where they are to be mixed, the mixing and the delivery of the concrete to the tower, elevator, conveyors, or other means by which the concrete is taken to its destination.

HAND MIXING

35. The arrangement of the apparatus required for mixing concrete by hand is shown in Fig. 2. In (*a*) are shown the mixing board at *a,* the water supply at *b,* a quantity of cement in bags at *c,* a pile of sand at *d,* and a pile of broken stone or other coarse aggregate at *e.* Boards *f* form a runway for the wheelbarrows by means of which the sand and coarse aggregate are conveyed to the platform.

36. Assume that a two-bag batch of stone concrete is to be mixed in the proportions 1 : 2 : 4. There will be needed 2 bags of cement, 4 cubic feet of sand, and 8 cubic feet of stone for each batch.

The 2 bags of cement are counted as 2 cubic feet. To measure 4 cubic feet of sand, a box is made which is 2 feet square, 1 foot deep, and without a bottom. This box is placed on the mixing board and sand is brought in wheelbarrows and dumped into it until the box is exactly filled. The sand in the box is leveled off and the box is raised by means of the projecting sides, which are formed into handles. The sand is then spread out in an even layer, and on top of this the cement is evenly spread as indicated in (*b*).

37. Laborers stationed at the points *x* and *y* begin to mix the cement and sand by each taking a shovelful and turning it over at the spaces marked *1* and *2*. The material is shaken off the shovels instead of being merely dumped off. Each man works on his own side of the dividing line *A A,* until all the cement and sand has been turned over. The operation is then reversed and all the material is shoveled back to the first position. The mixed cement and sand are then in a layer on one side of the board, as indicated in (*c*).

38. A stone-measuring box *a,* 2 feet wide by 4 feet long and 1 foot deep, which will hold exactly 8 cubic feet, is placed

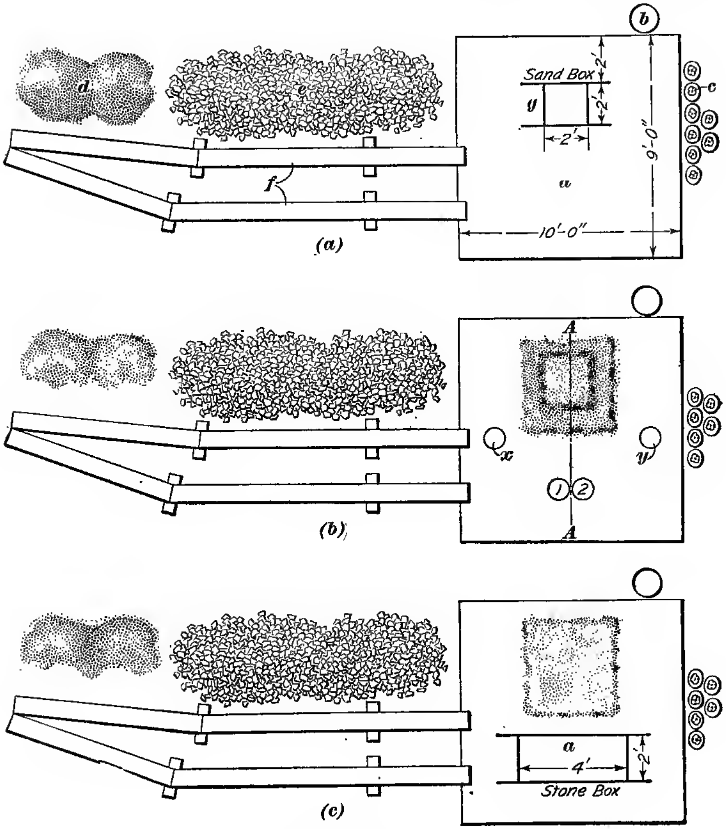


FIG. 2

alongside the sand-and-cement mixture and filled from the supply pile of stones. This box, which is also without bottom, is lifted up and removed, and the stone is shoveled over the sand-and-cement pile. The mass is then turned over as before, water being added gradually from a bucket. This turning operation is repeated three times, after which there should be no streaks of different color in the pile, but the entire mass of concrete should be of uniform color and consistency. The concrete is then shoveled into wheelbarrows and wheeled to its destination.

39. As has been stated under the heading of Proportioning of Mortar, the measuring of the aggregates is usually done in wheelbarrows instead of boxes, although the method of using boxes is more accurate. The use of the wheelbarrow is economical in time and more convenient, but it is advisable to specify that the materials shall be mixed by the use of boxes, though the contractor may be allowed to use the wheelbarrow method as long as it is carefully done.

The contents of the wheelbarrow should be accurately ascertained so that the amount of aggregates shall be in proper proportion to the cement.

MACHINE MIXING

40. Mixing Machines.—There are two types of mechanical concrete mixers, known as *batch mixers* and *continuous mixers*. The batch mixers are designed to receive a given quantity or batch of materials, which is placed in the machine, thoroughly mixed, and discharged into buckets or wheelbarrows. The machine is then supplied with a new batch of materials and the process repeated. In the continuous mixers, as the name implies, the materials are supplied, mixed, and the concrete is discharged continuously, unless the machine is stopped. In these mixers there is always a possibility that the spouts, bins, or hoppers, from which the various materials are fed to the machine, may become clogged or stopped up, thus causing the ingredients to be fed in different proportions than were intended. This may lead to serious imperfections in the quality of the concrete.

41. Batch Mixers.—There are several kinds of batch mixers, one of the most common forms of which is illustrated in Fig. 3. At *a* is shown a receptacle, called an *automatic skip, side loader,* or *pivot hopper,* into which the amounts of cement, sand, and stone necessary to make one batch are dumped. The skip is then elevated by means of ropes and pulleys to the position shown by the dotted lines *b*, when the materials will slide out into the drum *c*. A measured amount of water is introduced from the tank *e*. The drum revolves and lifts the cement, sand, and stone up inside the drum by means of blades that are riveted to the inside. When the material reaches the top of the drum it is dropped to the bottom and picked up by other blades. This process is rapidly repeated and the materials become thoroughly mixed.

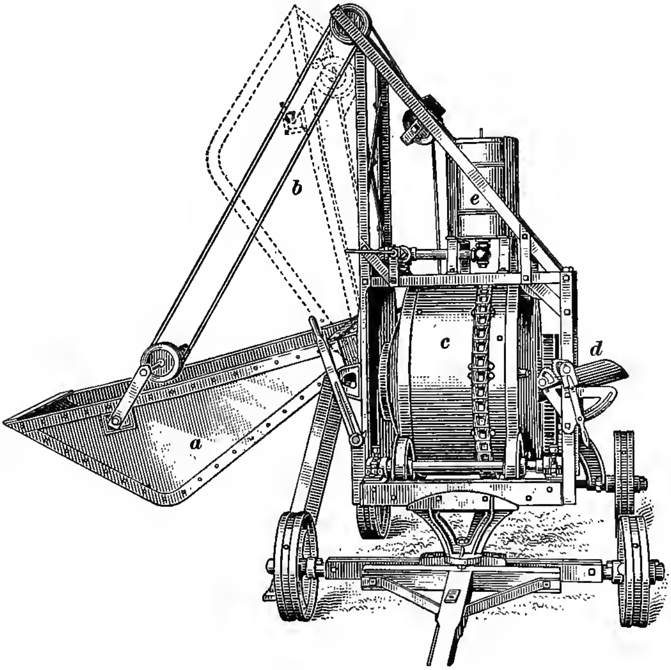


FIG. 3

To discharge the mixed concrete, a small chute *d* is swung into the opening on the side of the drum opposite to that from which the materials enter and the concrete falling upon the upper end of this chute slides out into wheelbarrows, conveyors, or buckets.

42. While the mixing is going on in the drum, the skip is lowered and measured quantities of materials to form another batch are placed in it. When the mixed concrete has been discharged, the skip is raised and the new batch is dumped into the drum and is mixed and discharged. It will thus be seen that this process is practically a continuous one, but that concrete of the proper proportions can always be obtained.

43. Batch mixers may be driven by steam, gasoline, or electric power. For very large work, mixers operating by the action of compressed air have been used, but the installation of such huge machines is too expensive for the class of work with which the architect is identified, being used mostly for purely engineering works such as tunnels and foundations requiring large quantities of concrete.

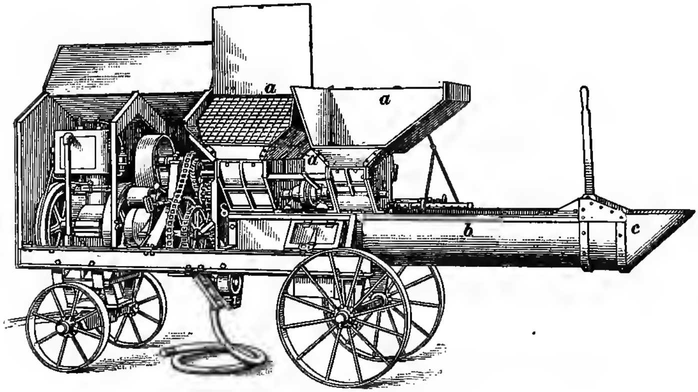


FIG. 4

44. Continuous Mixers.—Continuous mixers usually consist of a feeding device and a trough in which is a screw that mixes and pushes the concrete from one end of the trough to the other. One form of such mixer is shown in Fig. 4. At *a* are hoppers that constitute the feeding device. These hoppers contain the cement, sand, and stone and are provided with slides which are used to gauge the amount of materials that are fed into the mixing trough.

The screw in the mixing trough *b* is not a solid screw which would merely push the materials forward, but is divided with blades which also mix the concrete while pushing it to the point *c*, where it is discharged. In this form of mixer the materials are shoveled into the hoppers, and special care must be taken that the hoppers do not become empty while the machine is in operation or the mixture will be deficient in some of the necessary ingredients.

45. Water Supply.—One important feature of all concrete mixers is the device for supplying water. In continuous mixers the water is usually fed to the concrete through a pipe over the mixing trough and extending parallel with it. This pipe is perforated with holes which allow the water to escape gradually so as to feed the water to the mixture along a portion of the length of the mixing trough.

In batch mixers, a tank *e*, Fig. 3, is usually mounted over the drum. This tank has an outlet into the mixer drum and every time the mixer is loaded a constant quantity of water is drawn from the tank into the mixer. The tank can be adjusted to give any desired quantity and so long as the setting of the adjustment is left undisturbed the tank will deliver the same constant amount of water to each batch, thus making for uniformity in the consistency of the concrete.

46. Mixing in Cold Weather.—If concrete is mixed in very cold weather, every precaution should be taken not to incorporate frozen materials in the mixture. This may be guarded against by heating the sand, stone, and water before they are placed in the mixer. The sand and stone are often heated by means of steam pipes which run through the piles, although any other method may be used which will be equally effective.

Concrete which is mixed and deposited during cold weather requires also to be protected against freezing. The manner in which this is accomplished will be described later.

CONVEYING OF CONCRETE

47. Methods Used.—Concrete may be delivered at the forms by any of several methods. It may be discharged from the mixer into wheelbarrows or carts and wheeled directly to the forms. It may be discharged from the mixing machine into wheelbarrows or carts which are raised by means of an elevator to the height required by the construction and wheeled from the elevator to the forms. It may be discharged from the mixer into buckets which are raised by an elevator to a desired height where the buckets are tilted automatically and the concrete discharged into a bin. From this bin it may be discharged into wheelbarrows or carts and wheeled to the forms or it may be discharged from the bin into spouts or chutes that are inclined sufficiently to cause the concrete to flow under its own weight down the chutes to the forms that are to be filled.

48. The method of wheeling directly to the forms is most commonly used on small structures or for those which are located below the level of the mixing equipment, as the wheeling of concrete can be undertaken only on a down grade or on the level. Elevating the loaded wheelbarrows or carts is employed when temporary lifts for hoisting materials have been installed in the building and can be used in hoisting wheelbarrows of concrete rapidly from the ground floor to the level at which it is to be poured.

49. When large quantities of concrete are required or the structure is of a large area, however, the elevator and a spouting system will be found to be a cheaper method of handling the concrete, since there is very little labor required and this saving in the cost of labor will offset the cost of the special equipment.

In the great majority of cases it becomes necessary to elevate the concrete before it is conveyed, and a concreting plant thus includes an elevating and distributing system as will be described later.

50. Wheelbarrows, Carts, and Cars.—Concrete is frequently wheeled by means of the familiar wheelbarrow propelled by a laborer. This method is, however, not economical, because only 2 or 3 cubic feet of concrete can be wheeled in a wheelbarrow without spilling. The concrete cart, Fig. 5, holds from 5 to 6 cubic feet, and since the load is balanced over the large wheels, the laborers have to exert themselves no more to convey the large amount in the cart than the small quantity in the wheelbarrow, if the runways are level; if the concrete has to be raised ever so little, the cart is too heavy for one man. If it is desired to wheel still larger quantities, the hopper car shown in Fig. 6 is used. This car is made in many sizes to hold from 15 to 54 cubic feet of concrete. It is always propelled by machinery, and runs on tracks. On the bottom is a gate *a*, with a handle *b* for its operation. The concrete issues from this gate in a wide stream but this stream is easily regulated, thus making it possible to fill thin walls directly from the car.

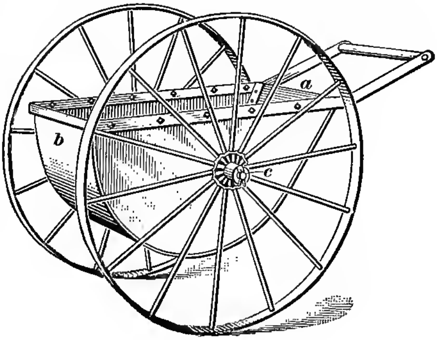


FIG. 5

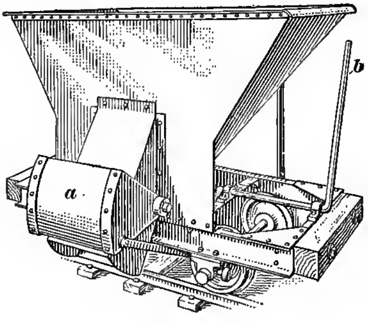


FIG. 6

51. Concrete Elevators of Wood.—A concrete elevator or tower, in which the concrete is raised in a bucket, is illustrated in Figs. 7 and 8. Such a tower is generally constructed of wood and consists of corner posts which are securely framed together and braced as shown at *a*. At *b* is a bucket which is hoisted up and down

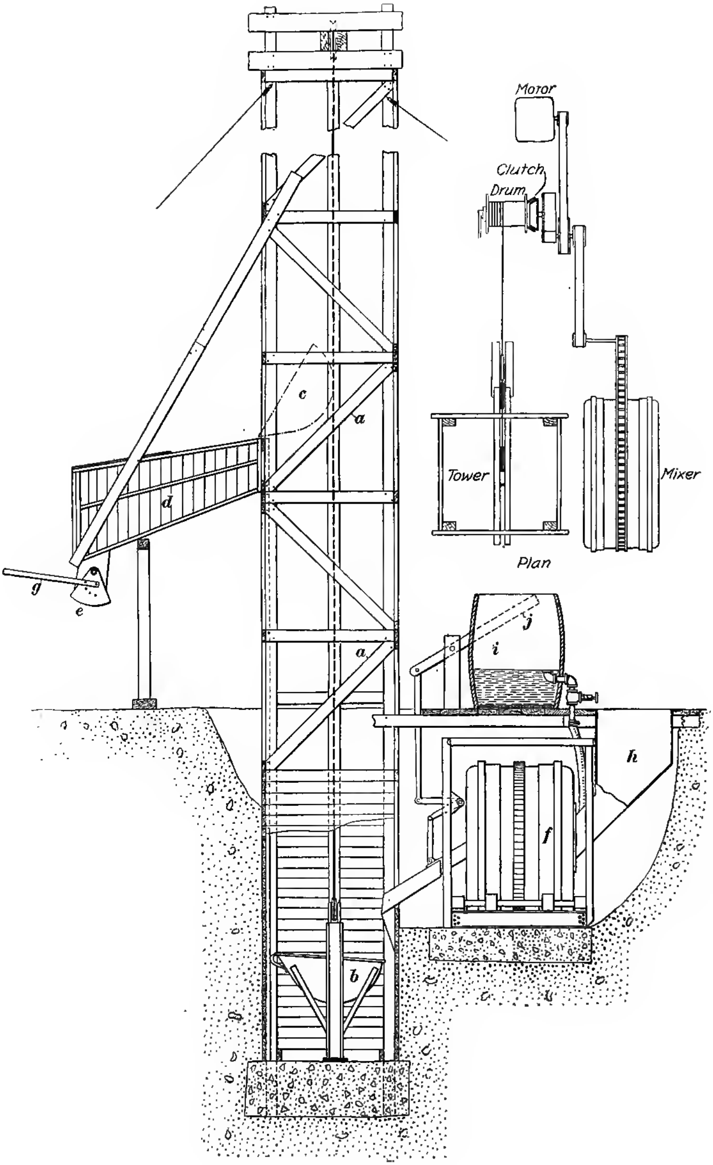


FIG. 7

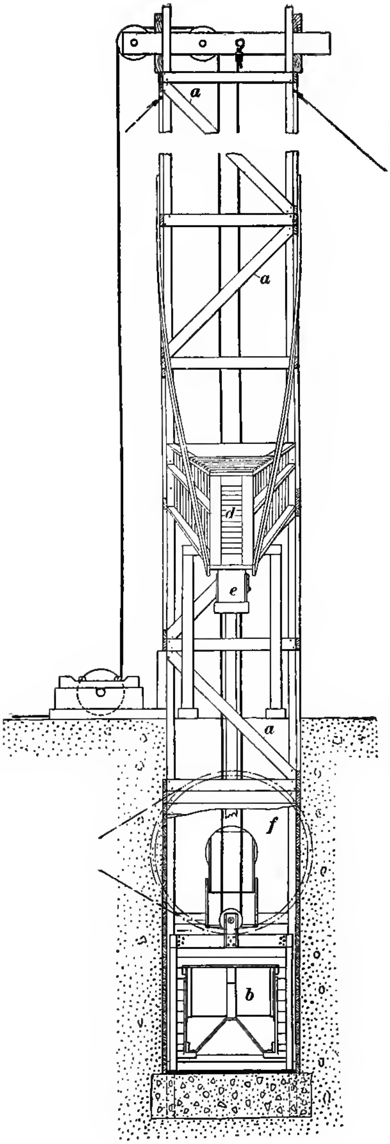


FIG. 8

in the tower and conveys the concrete to the desired level. As shown at *b* it is in the position where it is filled with concrete from the batch mixer *f*; it is also shown dotted at *c* in its position when discharging the concrete into the hopper *d*. From the hopper the concrete is discharged into carts through the gate *e*, which is opened and closed by the lever handle *g*. To prevent delay, the hopper *d* is designed to hold a supply of concrete so that the carts can be loaded while the bucket *b* is being refilled.

The ingredients for making the concrete are dumped into the chute *h*, which deposits them directly into the mixer *f*. The water is supplied from the barrel *i*. When the batch has been mixed, the handle *j* is raised as shown and the mixed concrete is deposited in the bucket *b*, which is then hoisted.

The mixer sets on a concrete platform, which is left in place when the building is finished. The posts of the tower are likewise supported in a bed of concrete. When the tower is removed the posts are cut off just above the concrete and the concrete base is left in the ground and covered up.

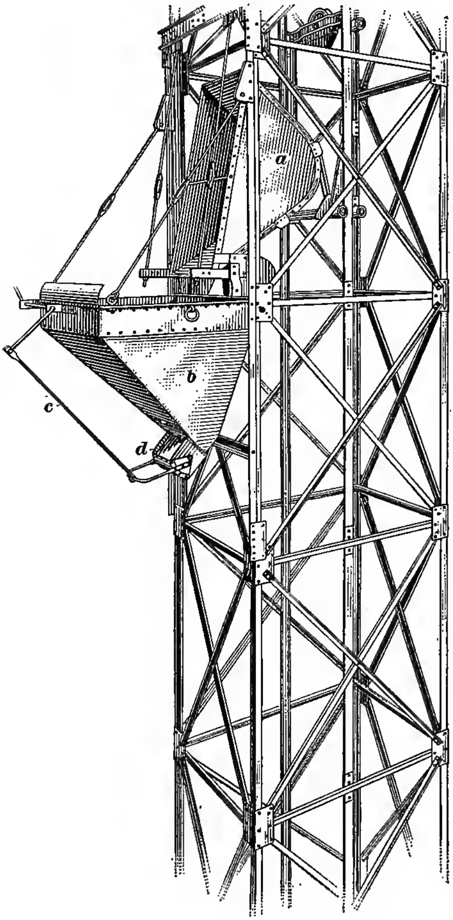


Fig. 9

To the right in Fig. 7 is a plan showing the relative positions of the tower, the mixer, and the motor which operates both.

52. Concrete Elevators of Steel. For tall buildings, elevators or towers formed of light rolled-steel shapes are often used. These are made in units of a given height which are connected to each other by means of bolts. After the building is completed the tower can be taken apart and the units stored for future use.

The initial cost of a steel tower exceeds that of a wooden one, but it has the advantage of being available for repeated use with very little expense, if properly taken down and cleaned after each structure has been completed.

53. In Fig. 9 is shown a portion of a steel-frame tower. At *a* is shown the bucket in a tilted position as it appears when the concrete is being discharged into the hopper *b*. In this illustration at *c* is shown the device that controls the discharge of the concrete from the hopper *b*, through the outlet *d*.

The mixers are sometimes placed immediately adjoining the tower on a platform that is elevated sufficiently above the grade level to allow the concrete from the mixer to fall into the bucket, which rests on the soil. In this method of handling the concrete, inclined runways are required between the sup-

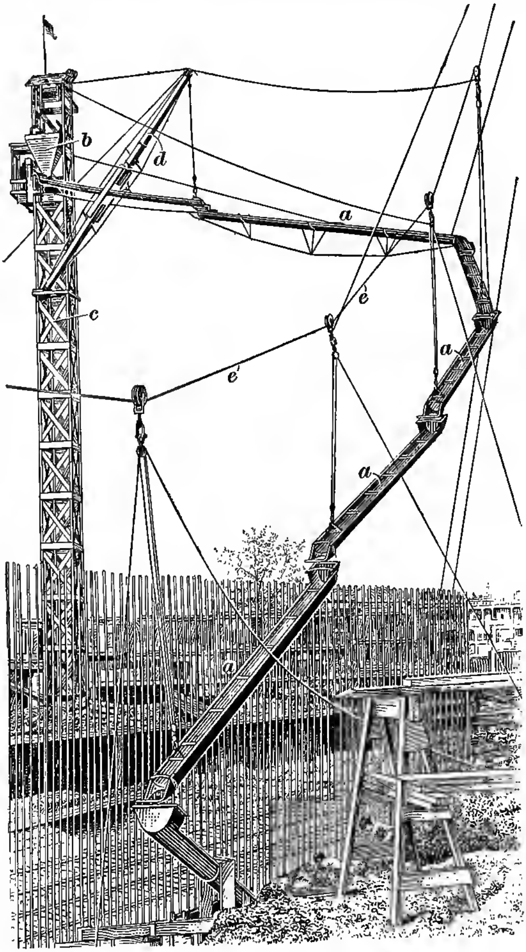


FIG. 10

plies of cement, sand, and stone, and the mixer, up which these ingredients must be wheeled or carted. Towers are sometimes located in a pit or in an excavated space. In such cases the mixer is placed at or below the soil level and the materials are dumped into it through a chute as shown in Fig. 7.

54. Spouting and Chutes. — *Spouting* consists of trough-shaped or pipe-shaped *chutes a,* Fig. 10. At the upper end, these chutes receive the concrete directly from the hopper *b,* which is attached to the tower *c* as has been described. The chutes are supported by means of booms *d,* on tripods, on cables *e,* or on brackets, as may be convenient. They are held in a sloping position so that the concrete will flow down them and be delivered at any desired point. The system of chutes is very flexible and the concrete can be delivered at any point around the tower within the distance reached by the end of the chute. This distance depends upon the number of sections of chute used and the height of the tower. The sections are from 10 feet to 50 feet in length and several sections can be used if necessary. Fig. 10 shows the use of seven sections, and illustrates the methods of using the chutes.

DEPOSITING CONCRETE

55. Separation of Ingredients.—In hauling concrete a long distance in cars or carts the vibration of the cars has a tendency to cause the coarse aggregates to settle at the bottom of the mass of concrete so that if it is deposited directly from the car the aggregates will occur in one part of the form and the mortar in another. This separation of the ingredients makes the concrete unsatisfactory. In dropping concrete from a considerable height, the stones have a tendency to separate from the mortar, which causes an unequal distribution of materials in the forms.

56. There are two important means that can be used to counteract these effects: One is to mix the concrete so as to make a stiff mixture in which the stones will not settle readily.

The second is to have the concrete dumped on a mixing board from which it is shoveled into the form. This latter method will remix the concrete just before it enters the form and thus insure satisfactory results.

In dropping concrete into a tall form, such as a form for a column or pier, it is a bad practice to dump the concrete directly from a barrow or cart into the form. The proper method is to shovel it carefully in. If the ingredients are somewhat separated in each shovelful, the mass will not be seriously affected.

The concrete should be sliced after being deposited in the forms, as will be described later. This treatment of the concrete after placing it in the forms helps to make it more uniform and compact.

57. Depositing From Spouting Systems.—When the spouting system is used to convey concrete for flat floor construction, it is the usual practice to discharge the concrete directly on the wooden forms and distribute it over a given area by means of rakes or hoes. If this method is used, the spout should be used to supply concrete for an area of about 300 or 400 square feet at one time and then moved to supply the next adjacent space. When an attempt is made to cover larger areas than this with the chute discharging in one spot, the concrete will have to be drawn through too great a distance with the rakes or hoes and will also tend to pile up too high under the chute. In such cases the liquid part of the concrete, consisting of water and cement, is apt to run out of the concrete and lodge in the lower parts of the adjacent beam and column forms. This liquid when it becomes hard forms a chalk-like substance that is called *laitance*. This laitance possesses little strength and the drainage of this liquid from the concrete leaves a mixture without the elements which are necessary to bind the aggregates together and which are essential to the formation of the concrete.

58. Methods of Depositing.—To secure the best construction, the concrete should be deposited in a continuous operation until an entire floor is completed. This is not always possible, however, and the method of procedure that is frequently followed is to cast the columns first and then cast the floor construction in sections. In this method the concrete is placed in the column forms to the height of the under side of the beam forms, the remaining part of the column and the beams being cast with the floor. In casting the floor, joints in the slabs are usually made midway between the beams where the one pouring is to cease; in the beams, midway between the girders; and in the girders, midway between the columns. These joints are formed by placing stop boards temporarily in the positions desired to prevent the concrete from flowing beyond these places. When ready to pour the next section, these boards are removed. In this method it is necessary to start each new section before the concrete of the preceding section has become hard, otherwise there will be no bond between the sections.

59. Handling.—The concrete mixture which is placed in the forms needs but little handling in order to fill the form, but what little handling is needed is indispensable in order to drive out the air which would otherwise be trapped in the concrete and produce voids. The purpose in all concrete work is to have the concrete as dense and compact as possible, and this is obtained only by eliminating the voids.

The air pockets often form rather large voids. There is, however, another kind of voids, which are very small and appear mostly at the surface of the concrete where it is in contact with the forms; these voids are caused by a local surplus of water which assembles in small globules and, upon evaporation, leaves empty spaces. Other very unsightly voids in the face of the work are those known as stone pockets; these occur where the mixture was imperfect to begin with or became imperfect through separation of the coarser aggregates from the mortar.

60. Slicing.—For the reasons mentioned, the manipulation of the concrete in the forms is a necessity. The most commonly used tool for this purpose is the *slice bar,* or spade, shown in Fig. 11, which is used as shown in Fig. 12. By inserting the blade between the forms and the concrete and pressing the coarse particles back into the body of the concrete, a dense skin of mortar is obtained at the surface. By working the blade up and down in the mass of plastic concrete in the forms, the air is driven out. By these two methods the concrete is made to lodge in the forms in a dense and well-packed mass.

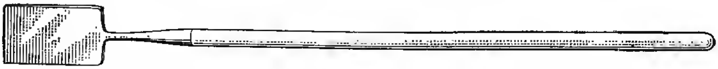


Fig. 11

In some cases it may be impossible, owing to the complicated forms, or other obstructions, to slice and work the concrete properly. In such cases, it is necessary to pound the outside of the forms with heavy wooden mallets, which has the effect of shaking the concrete down and giving the air an opportunity to escape.

61. Wetting.—Since water is such a necessary part of the concrete and since without it the cement cannot harden, it becomes very necessary to guard the concrete against drying too rapidly, especially in summer. Concrete contained within forms is not affected under ordinary conditions, but the surfaces of floors and pavements present such a large area to the rays of the sun that the concrete is affected unfavorably. The remedy is to cover the concrete with boards, straw, or moist earth and to keep the concrete and its covering wet by sprinkling for several days after it is laid.

62. In Freezing Weather.—Concrete that is deposited in cold weather requires to be protected against freezing. A floor or sidewalk construction is usually covered with a heavy tarred paper on which is placed a quantity of hay or straw, and boards laid on this to hold it in place. Canvas is sometimes used to form a covering over a floor and is supported on a framework of wood. This framework is made sufficiently high

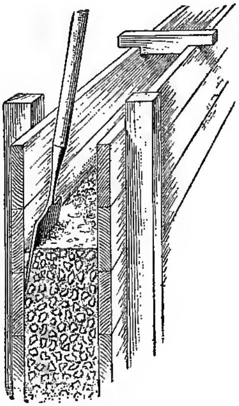


Fig. 12

so that salamanders may be placed beneath the canvas and fires be kept burning so as to maintain a temperature that will be above the freezing point. In addition to this protection for the floor construction, the sides and ends of a building are often enclosed with large sheets of canvas, and salamanders are placed in the story below the newly formed concrete floor. This method of heating produces a warmth under the floor construction and facilitates the setting of the cement in the concrete floor, beams, girders, and columns.

While concrete which has been frozen will usually harden in a satisfactory manner after thawing out, repeated freezing and thawing will injure it.

Another danger is that frozen concrete may be mistaken for hardened and seasoned concrete and the forms removed before the concrete is sufficiently strong to be self-supporting. To determine whether concrete is frozen or hardened, pour a quantity of hot water upon the concrete and if the concrete remains hard, it has set, but if it softens, it is frozen.

PLAIN, OR MASS, CONCRETE

63. Definition.—By **plain, or mass,** concrete is meant concrete in which reinforcing steel is not employed. It is used in the more bulky or massive parts of a structure such as the footings and foundation walls of buildings, and in retaining walls. Mass concrete is poured into prepared forms or molds and is allowed to harden, after which the forms are removed. Mass concrete is also used in making sidewalks, pavements, and floors.

APPLICATION OF PLAIN CONCRETE

64. Footings.—The footings used in building work may be considered under two divisions, namely, *column* or *pier footings,* and *wall footings.*

65. Column Footings.—Column or pier footings are placed under columns or piers and support a single concentrated load.

The simplest type of column footing, shown in Fig. 13, consists of a single layer of concrete *a*. Upon this layer a pier *b* may rest directly as shown. The thickness *d* of the footing is determined by the amount of projection *c*, and should be one and three-quarters to twice the distance *c*. If the projection is made greater than these amounts it may break off when the load is applied on the pier.

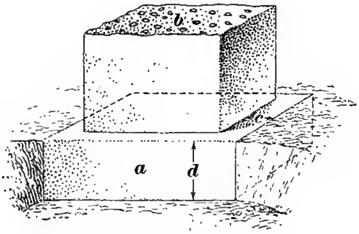


Fig. 13

66. Stepped Footings. Where a greater projection of the footing is required, which will be the case when the load is to be greater or where the supporting soil is soft, the thickness of the footing must be increased. Instead of building the footing in a single cube-like mass, it may be made, as illustrated in Fig. 14, in steps, thereby saving considerable concrete. The concrete omitted

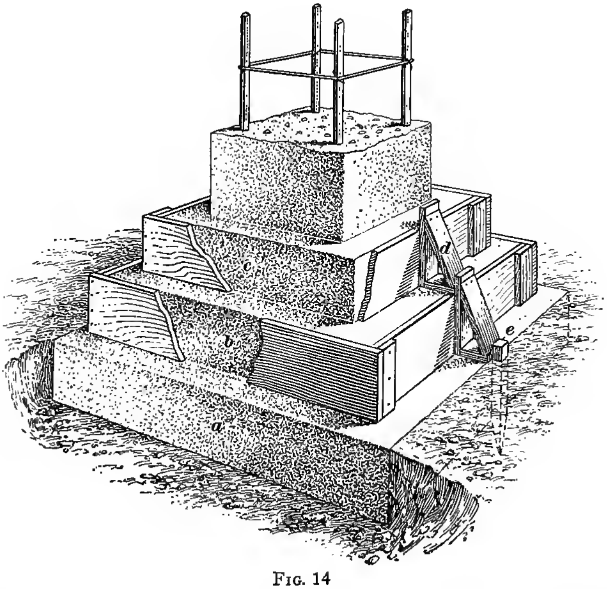


Fig. 14

from above the steps does not detract from the strength of the footing. The footing shown in Fig. 14 is formed of three steps, each of which is cast separately. The lowest step *a* is cast in a mold or form made by digging a rectangular hole in the ground and filling it with concrete. The second step *b* is next cast in a wooden form, as is also the step *c*.

The forms for these steps are shown broken away, to illustrate their shape and the method of using them.

67. Tapered Footings.—In Fig. 15 is shown a tapered footing *a*, which for the same size of top and bottom surfaces and the same height is just as strong as the type shown in Fig. 14.

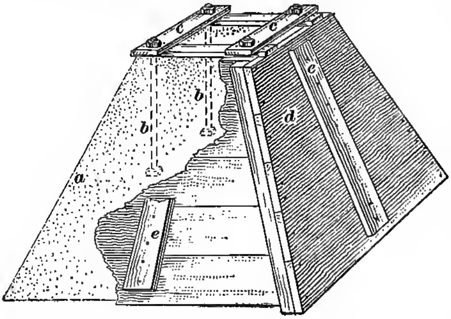


Fig. 15

68. Footings for Steel Columns. Where steel columns are to stand upon concrete footings it is necessary that they be securely bolted or anchored to the footing. This is done, as shown in Fig. 15, by means of steel bolts *b* which are embedded in the concrete and project above the top surface of the footing and through the bottom plate of the column, thus making a strong connection. The bolts must be accurately set in the concrete in such positions that when the column is set on the footing they will enter the holes in the column and can be secured by nuts. The bolts are located accurately and kept in place while the concrete is being poured, by use of a wooden templet, or pattern, *c*, in which holes are bored at proper points to receive and hold the bolts, and this templet is securely fastened to the top of the form *d* in which the footing is cast. The position of the footing and templet must be very carefully located, and they must be set true as regards the lines and levels which regulate the positions and the levels of the under sides of the column bases.

69. Wall Footings.—A concrete wall footing is a layer of concrete which is placed on the soil for the wall to rest upon. The thickness of the footing depends upon the distance that it projects beyond the face of the wall, and is determined by the same rule as that given for column footings. Concrete footings are often used for walls that are constructed of other materials, such as stone or brick, as well as for concrete walls.

An example of the use of a concrete footing for a concrete foundation wall of a dwelling house is shown at *a* in Fig. 16.

70. Plain - Concrete Walls. — Plain - concrete foundation walls of buildings are usually buried underground for their greater part, and the portion below ground needs no special ornamental surface treatment. The portion of the foundation wall above ground, also the walls of the superstructure, when formed of concrete is generally given an ornamental surface treatment.

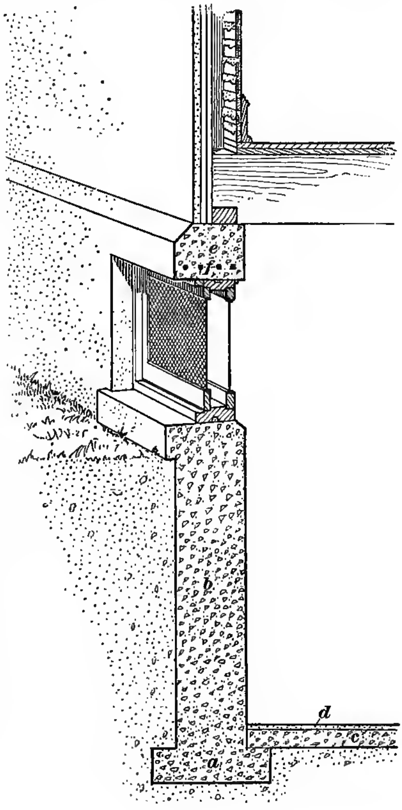


Fig. 16

71. In Fig. 16 is shown a section through a plain-concrete cellar wall. This wall stands on a simple footing course *a*, and the part of the wall below the surface of the ground is shown at *b*. The part of the wall above the ground contains the windows that give light to the cellar, and above the window shown is formed a concrete lintel that is reinforced by means of the steel bars shown in section at *f*. A cellar floor of concrete is shown at *c* and the finished wearing surface of the floor at *d*.

72. Retaining Walls. — Another use for plain or mass concrete is in building *retaining walls*. An example of a retaining wall which serves to hold up a small terrace is given in Fig. 17. At *a* is shown the finished wall; at *b*, a coping which projects beyond the face of the wall to shed rain, as well as to form a finish for the wall. A similar wall without coping is shown at *c* on each side of the steps.

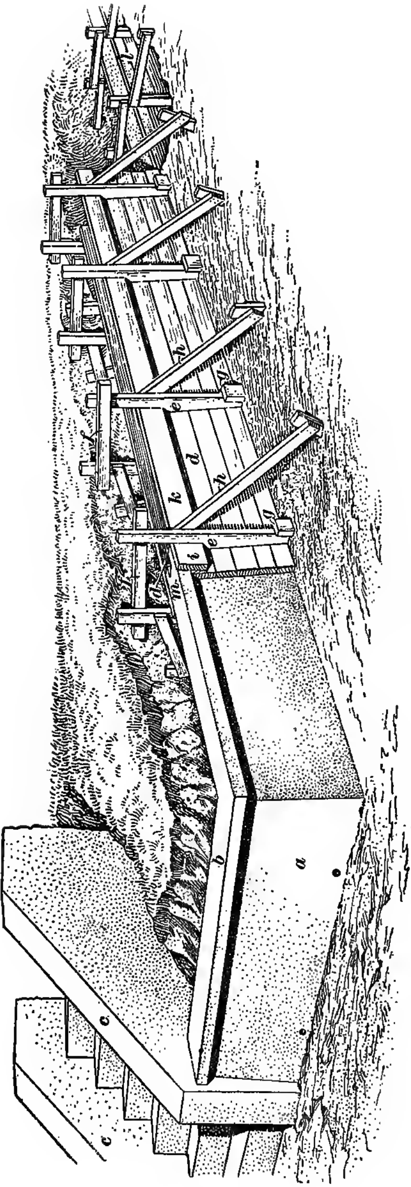


Fig. 17

73. A cross-section of this retaining wall is indicated in Fig. 18, the part above ground and the outline of the terrace back of the wall being shown dotted. Behind the wall, just below the coping *d*, is shown a gutter *e*, which serves to catch the water that flows down the terrace and lead it away so that it will not seep down back of the wall. Any water that does

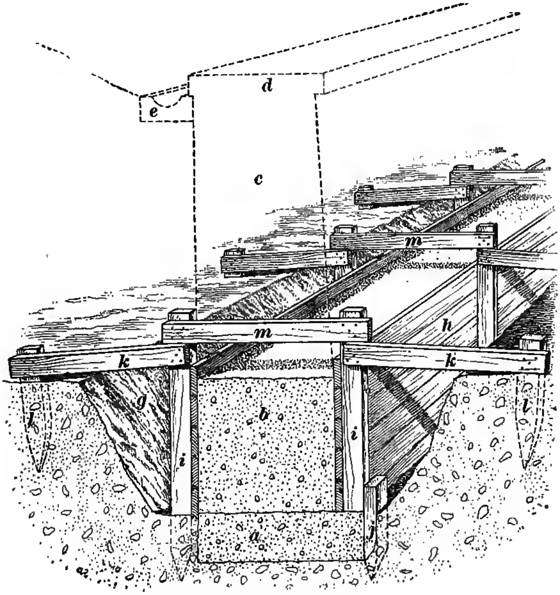


FIG. 18

penetrate the earth behind the wall can escape through the pipelike holes formed in the wall just above the grade, as shown in the wall *a* in Fig. 17.

After the wall has been completed the soil is filled in back of the wall as indicated by the dotted outline in Fig. 18. The part filled in is sometimes called the *back fill.*

FORMS FOR PLAIN CONCRETE

74. Forms for Footings. — A form is not usually required for the construction of a footing such as is shown in Fig. 13, as a space the exact size of the footing can generally be excavated in the soil and filled with concrete. When, however, as in gravel or sand, the sides of the excavation will not remain vertical, wooden forms are used. A form for a footing such as shown in Fig. 13 may be made of four boards cut to the required lengths and nailed together in the form of a box. Stakes, driven in the ground outside such a form, hold it in place and prevent the sides from bulging when the concrete is poured into it.

75. The form for a footing such as shown in Fig. 14 is made in sections. If possible, the form for the lowest part of the footing *a* is made in the soil without the use of wood. If the sides of the excavation will not stand up, board forms must be used for this section. In either case forms must be provided for the sections *b* and *c* somewhat as shown in the figure. These forms are held in position by braces *d*, which are fastened to the stakes *e* and to the forms.

76. A part of a form for a tapered footing is shown at *d* in Fig. 15. This form is made of planks having their ends cut to a bevel as required by the shape of the footing. The planks of each side are held together by means of battens *e* and the sides of the frame are also nailed together at the corners. Interior cross-braces are sometimes used to preserve the shape of the form until it is set in place, after which they are loosened and removed through the open top of the form before the concrete is poured.

77. Forms for Piers. — Fig. 19 illustrates several methods of making forms for piers. The four sides are built of planks running vertically. These sides are held together by the different devices shown. In all these, iron or steel bolts are employed; and wooden wedges are freely used to bring the various parts tightly together. In the lower right-hand illustration is shown the use of angle irons fitted to the corners of the form and drawn together by means of bolts.

The main object of these pier forms is that they shall confine the mass of concrete so that it will not move or spread out the sides of the forms, and that the finer parts of the concrete will not leak out. They are also made so that they can easily be taken down and used as forms for other columns. Further reference to forms for piers and columns will be made later. Other designs for forms will also be shown under the heading Reinforced Concrete.

78. Forms for Walls.—The forms used in the construction of a low retaining wall of plain, or mass, concrete are shown in Fig. 17. The wall is indicated in cross-section in Fig. 18, in which *a* is the footing, *b* the wall below ground, *c* the wall above ground, and *d* the coping member.

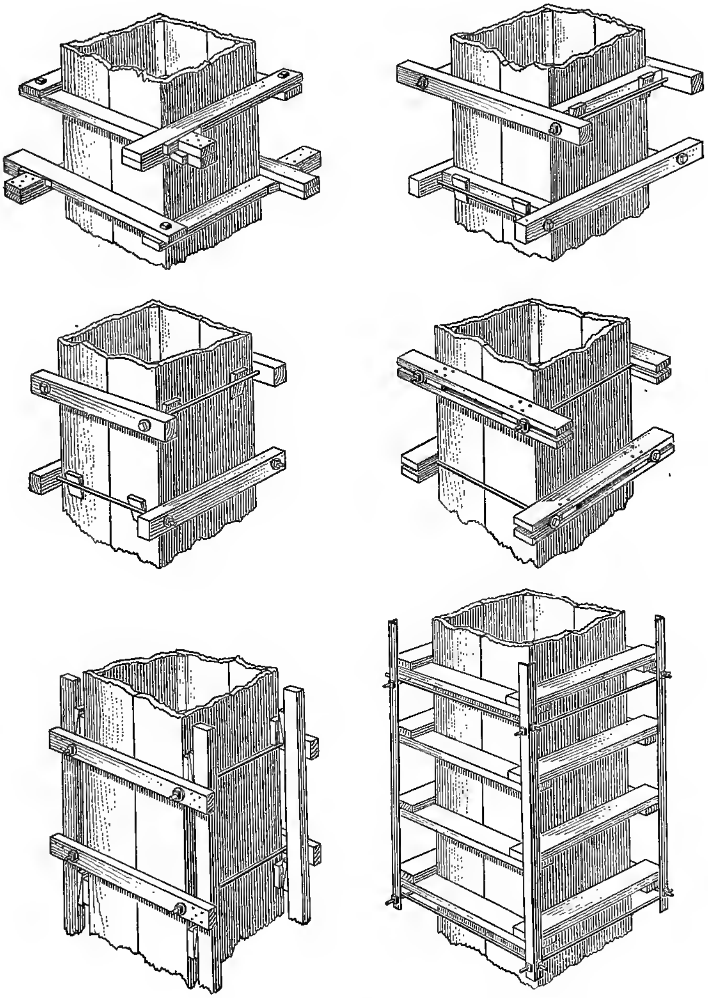


FIG. 19

The footing *a* is poured first, the earth being excavated to act as a form. Large-sized stones are sometimes placed in the footing and extend above its surface so as to tie the footing to the section *b*.

The excavation for the wall, as a whole, should be made of sufficient size to permit workmen to set the forms required for the portions of the wall above the footings.

The section *b* is cast in forms that are constructed as shown. The boards *h* are nailed to the uprights *i* and these are then set in place. They are held in the proper position by stakes *j* driven into the ground and by braces *k* that are nailed to them and to the stakes *l* driven at convenient points in the adjacent bank.

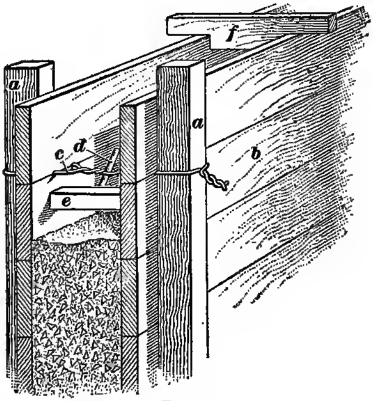


Fig. 20

Spacers *m* nailed to the uprights *i* keep the two faces of the form at the correct distance apart.

79. When the lower section of the whole wall has been finished and has had time to set, the form work is removed and the earth is shoveled and tamped into place against the wall and the forms are set for the top section of the wall as shown in Fig. 17.

80. The form used for this section of the wall consists of planks *d*, fastened to posts, or battens, *e*. The battens are held in place at the top by the spacers *f* and at the bottom by the stakes *g*, which are driven into the ground. They are further braced by the inclined braces *h*. The form is constructed to allow for the coping as shown at *i*, the battens being cut in the shape shown and the board *k* nailed outside of the lower boards *d*, thus providing for this projection.

81. Another type of wall form, for comparatively thin walls of considerable height, is shown in Fig. 20. The battens *a*, which support the planks *b*, are held together by means of wires *c* that pass between the planks and are twisted by means of sticks *d* and tend to pull the forms together. To prevent their being pulled together too closely, spreaders *e* are placed close to the wires. These spreaders are removed as the concrete reaches their levels, as they are no longer needed, the concrete being sufficient to keep the forms apart. Spacers *f* are also used at the tops of the forms to keep the forms the proper distance apart.

After completion of the concrete work, the wire ties are cut and the forms removed, and the projecting ends of the wire ties are then dressed back as closely to the face of the wall as possible. They will, however, rust in time and stain the walls, therefore methods that permit of the iron ties being removed entirely are preferable for work that will be seen.

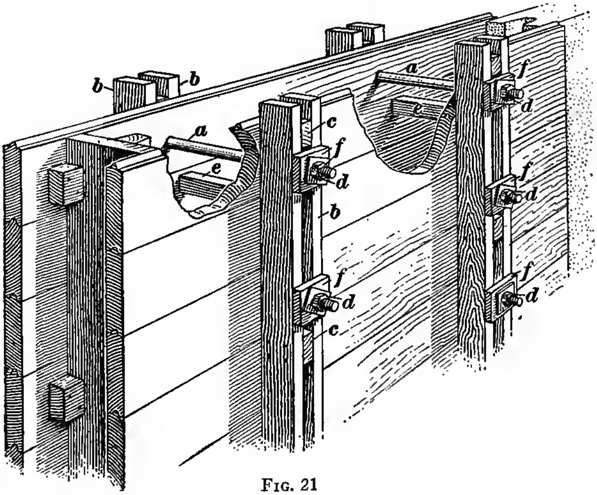


Fig. 21

82. A method by which the forms are held together by bolts instead of by wire ties is illustrated in Fig. 21. Here bolts *a* extend through battens, or posts, formed of two pieces *b* kept about 1 inch apart by means of blocks *c* nailed between them. On the ends of the bolts are applied iron washers and nuts *d* by which the battens are firmly held. The bolts are made of sufficient length to serve for the thickest walls that are to occur in the building, and when they are used for thinner walls the difference in thickness is taken up by means of blocks of wood *f*. Wooden *spreaders e* are used to keep the sides of the form apart and are removed when the concrete reaches their levels. As soon as the wall has set and the forms have been removed, the bolts are withdrawn. There will then be no iron left in the wall to cause rust stains.

83. Steel Forms.—There are on the market many patented types of metal forms for concrete wall construction. One class consists of small units and provides for the casting of only a small amount of concrete at one time. Forms of this class are generally used for the construction of the walls of houses and other small structures. The concrete is mixed quite dry, the forms are filled by hand and the concrete thoroughly tamped to secure a compact mass. Immediately after this is accomplished, the form is removed, placed elsewhere, and another section of wall is cast.

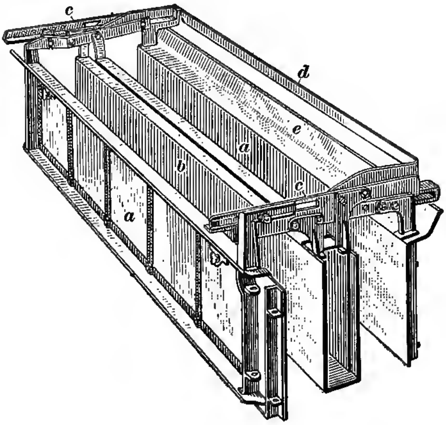


Fig. 22

Another class of steel forms, which may consist of small or of large units, provides for casting a large quantity of concrete at one time and is used where large masses of concrete are to be placed. The concrete is poured into the forms, which are left in place until the concrete has hardened, after which they can be removed and used for building other parts of the wall.

84. In Fig. 22 is shown an example of a metal form for casting a hollow concrete wall. It consists of the outside plates *a*, and the partition *b*, which forms the space between the outer and inner parts of the wall. The cross-bars *c* are adjustable and allow of making the outer and the inner shells of the wall of different thicknesses. The flanges *e* are spread so as to prevent pouring the concrete over the outside of the form. At *d* is shown a handle which can be raised to a vertical position and is used to lift the entire form so as to remove it from the wall.

85. In Fig. 23 is shown a portion of a concrete wall in the process of construction by use of the form just described. At *a* is the outer shell of the wall, at *b* is the steel form in position and being filled with concrete. Recesses *c* are shown in the wall to receive the floor joists. These recesses are formed as shown at *d* by inserting temporary wooden blocks in the proper positions when filling the steel form. At *e* is shown one of these temporary blocks partly removed. Wooden strips *f* to be used as nailing pieces to which woodwork can be secured can be placed in the mold at any desired point.

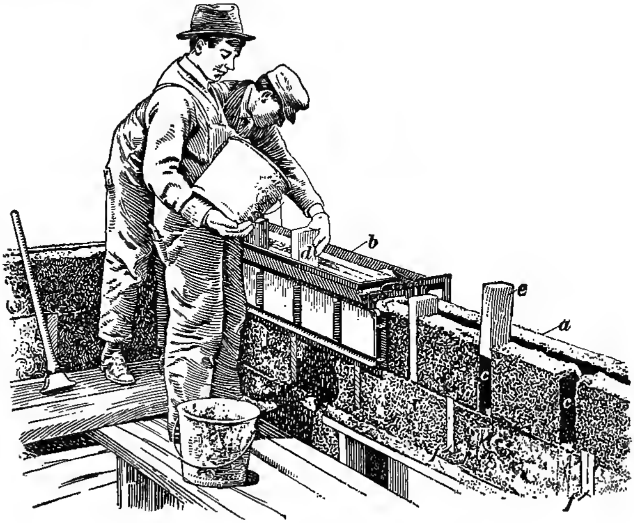


FIG. 23

86. Fig. 24 shows a portion of a completed wall *a*. The form *b* has just been raised and is about to be placed on the wall to form a new section. It will be placed so as to cover the sloping end of the part just completed. A course the depth of the machine is cast around the building. By the time this is done the portion of the course that was cast first will be hard enough to receive a new course on top of it. This course is carried around the building in the same manner.

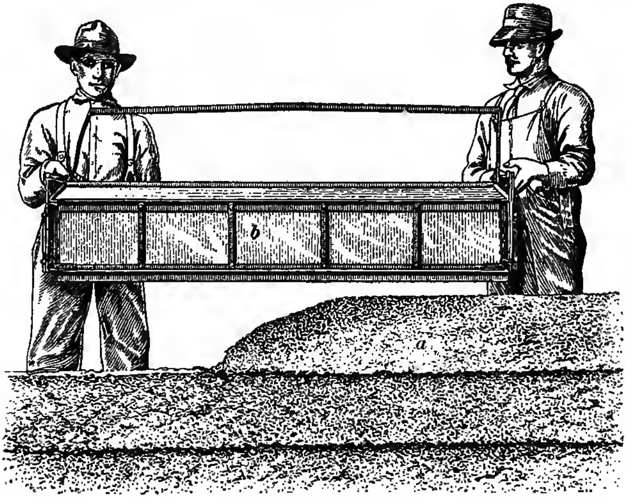


FIG. 24

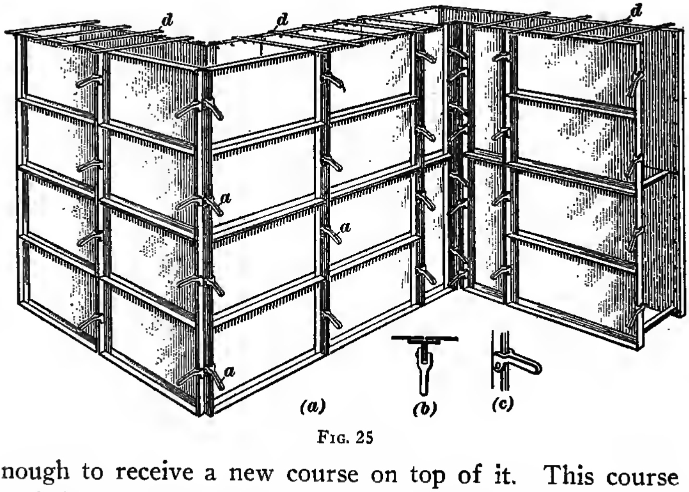


FIG. 25

87. Fig. 25 shows a form consisting of units made of galvanized sheet iron with angle-iron frames, which are assembled, locked together, tied, and braced in such a manner that they are rigid and sufficiently strong to resist the pressure of concrete in large masses. They are fastened together by the clamps *a*, which when raised up as shown cover the angles of the two adjacent units and hold them together. The clamp is shown separately at *b*, where the observer is looking down upon it, and at *c*, which is a perspective view. The rods *d* are called *stay-rods* and are adjustable to hold the plates at the proper distance apart. The smooth surface of the galvanized iron gives a smooth finish to the surface of the wall. In Fig. 26 is shown a building in process of construction in which this type of sheet-metal form is being used.

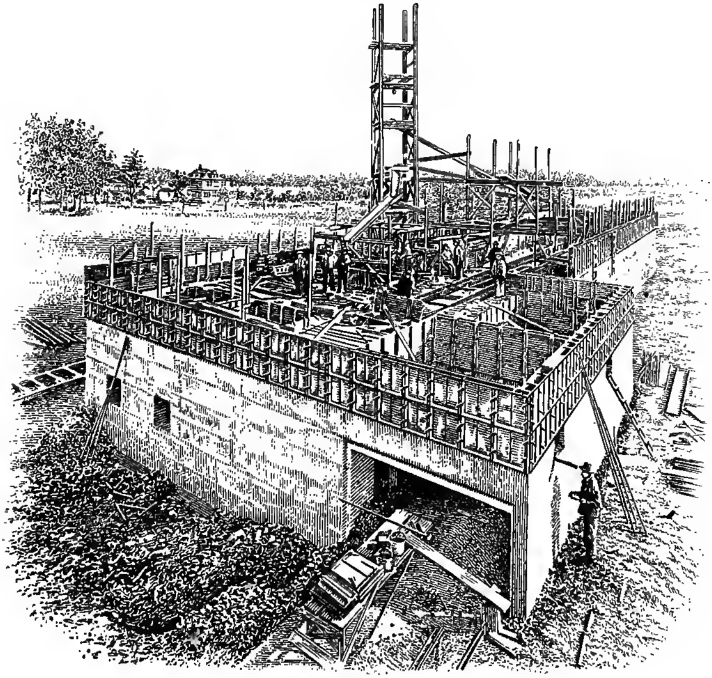


Fig. 26

88. Forms constructed of pressed-steel uprights *a* are shown in Fig. 27. The forms between these uprights are made of sheets of steel stiffened by the wooden planks *b*, which are secured to the backs of the steel plates. These forms are light in weight, are easily handled, and are especially adapted to the construction of structures that require large masses of concrete, such as retaining walls, of which Fig. 28 is an illustration.

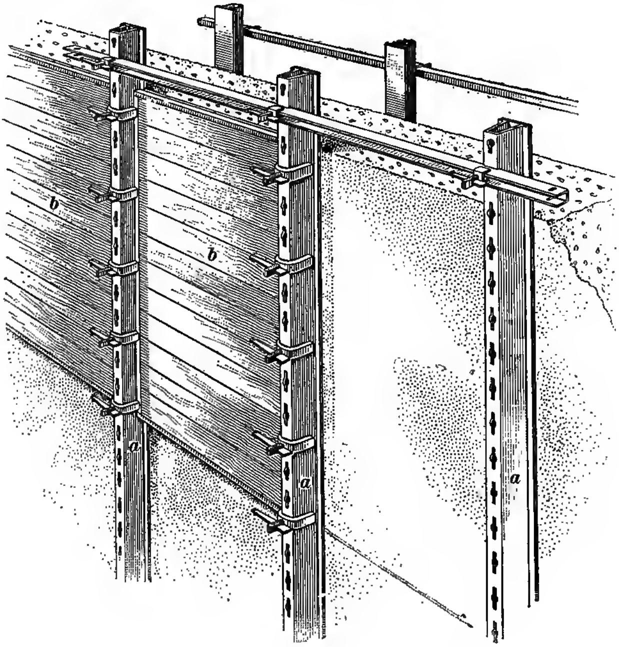


FIG. 27

89. Forms for Steps.—Steps are built in forms such as are shown in Fig. 29, in which *a* indicates the concrete treads and platform, and *b* the boards that form the risers. The side forms, shown at *c*, consist of boards nailed to battens. These battens are held in place by the blocks and braces *d*. Special bracing is provided at *e* to prevent the riser boards from bulging when the concrete is placed in the form.

90. Expansion Joints.—Long retaining or other walls are provided with what are called *expansion joints* at intervals of from 35 to 50 feet. These joints allow the wall to expand and contract with the change in temperature. An expansion joint is shown in the wall in Fig. 17 at *m* and in detail at *a* in Fig. 30. A form for such a joint is shown in Fig. 21.

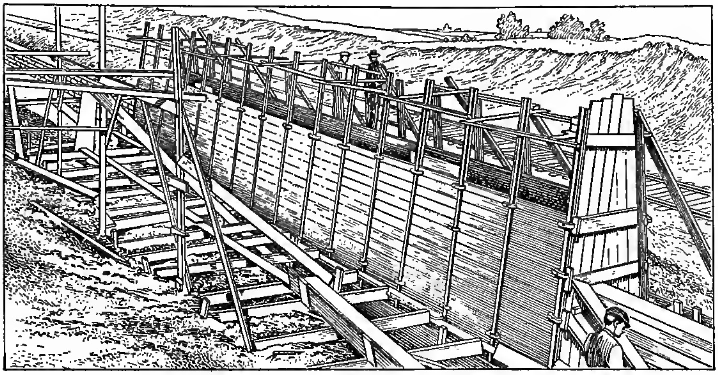


Fig. 28

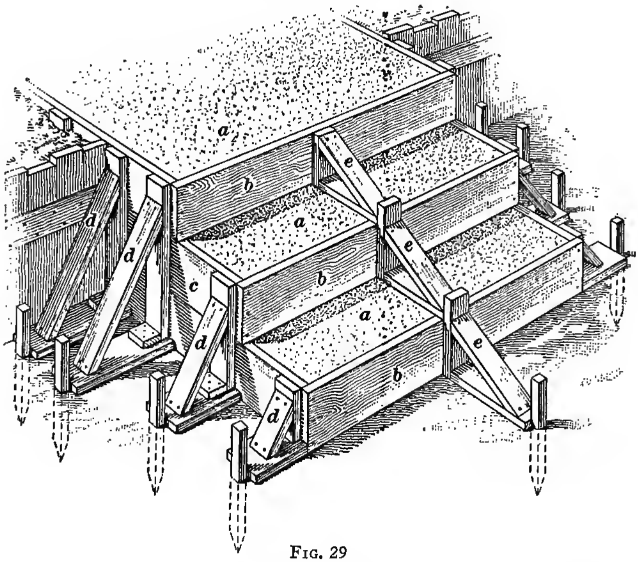


Fig. 29

In order to prevent the face of one section being pushed beyond the face of the adjacent section, the joint is formed with a tongue-and-groove construction. The end of the finished section is greased or covered with a layer of tar paper before the next section is cast against it.

91. Assembling and Removal of Forms.—Wooden forms for small structures are assembled as already described. Wooden forms for large structures are described later under Reinforced Concrete, as is also the removal of the forms and the care that should be taken of them to permit of their repeated use.

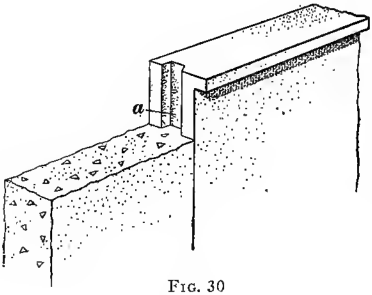


FIG. 30

The manner of assembling and removing forms of the patented types depends entirely upon the character of the forms, and the manufacturers provide detailed instructions relative to the use and care of their products. Forms of this character are usually designed so that the units are interchangeable, and also adjustable, hence the forms may be used in the construction of walls of various thicknesses and heights.

SURFACE FINISHES FOR WALLS

92. Concrete, when placed, fills every irregularity of the forms, and when the forms are removed the imprints of any defects are plainly visible on the concrete. Therefore, if it is desired to have a concrete of uniform surface, the first requisite is a form without defects or blemishes of any kind. Such a form cannot be made of wood; only steel forms are sufficiently smooth to leave no marks on the concrete.

Even when steel forms have been used, there are defects in the wall surfaces where the units, which compose the forms, adjoin each other. Furthermore, concrete is not always acceptable for high-class work because the concrete itself has a dull grayish color which is very monotonous, and when wet it becomes streaked and blotched.

93. Methods of Finishing. — There are various methods of obtaining uniform and pleasing surfaces on concrete walls. One of these consists of washing or brushing the surface before the concrete has thoroughly hardened. Another is to tool or sand-blast the surface after it has become thoroughly hardened. A third method is to apply a facing of special concrete to the form by means of a trowel and back it up with ordinary concrete. This facing can be made of white cement mixed with marble dust, special colored aggregates, etc. These methods produce agreeable and artistic results.

94. A facing material of mortar containing one part cement and two parts of fine aggregate, such as marble screenings or colored sand, is often used. Mortars for facing should never be made richer than 1 part cement and 2 parts sand or screenings. If gravel or fine stone is to be added to the cement and sand, for a facing, the mixture may be made in the proportions of 1 : 1½ : 3 or 1 : 2 : 3. If coarse aggregate is used, the minimum thickness of the facing should be not less than twice the maximum dimension of the largest pieces of stone.

95. Surface Finishes.—Surfaces of plain concrete walls may be **brushed.** In this treatment the forms must be removed within 12 hours after the concrete is poured; then, while the surface is still comparatively soft, it is brushed with a bristle brush to remove the mortar from the surface and leave the coarse aggregate exposed. An acid wash may be applied after the brushing in order to remove the film of cement that may adhere to the stone. Such a wash should be a very weak solution of muriatic acid, and after it has been used, the acid should be carefully washed off the wall by a liberal use of clean water.

96. Rubbed Surface.—If a rubbed surface is desired, the forms are removed from the wall after the concrete is a day or two old and the surface is rubbed with a brick formed of carborundum or emery, or with a piece of soft sandstone. A good rubbed surface is secured when the facing mixture contains little or no coarse aggregate. A thin grout composed of cement and sand should be applied during the process of rubbing and the surface afterwards washed down with clean water.

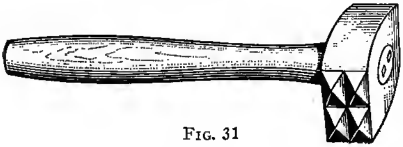


Fig. 31

97. Sand - Blasted Surface.—A sand-blasted surface has very much the same texture and finish as that obtained by brushing. This treatment is applied, however, after the concrete has become hard. Any pronounced ridges or irregularities in the surface should be removed by tooling, and cracks or open joints should be pointed some time before the surface is sand-blasted, in order that the filling may be hard.

98. Tooled Surface.—Concrete surfaces may be finished by tooling by any of the methods and in any of the styles employed for finishing natural stone. Where a surface is to be tooled, the best results are obtained when a facing material with comparatively small-sized aggregates is used, as it is hard to dress and to obtain uniform results on surfaces when large stones are encountered. Concrete should be thoroughly hard before being tooled, especially if sharp edges and surfaces of a fine uniform texture are desired.

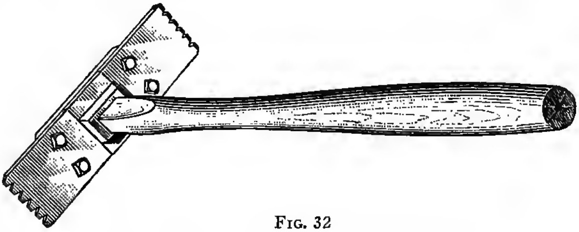


Fig. 32

99. Tools.—Tools that are frequently used for surfacing concrete walls are the *bush hammer*, shown in Fig. 31, and the *concrete ax*, shown in Fig. 32. Where compressed air is available, the concrete may be dressed with a *pneumatic hammer,* which gives excellent results in the hands of an expert.

100. Examples of Surfaces.—An example of concrete facing containing an aggregate of trap rock and having a *brushed surface* is shown in Fig. 33. A surface dressed with a pneumatic hammer is shown in Fig. 34. The effects obtained by the use of the bush hammer or the ax are about the same as those obtained with the pneumatic hammer, but are not quite so regular and uniform in texture.

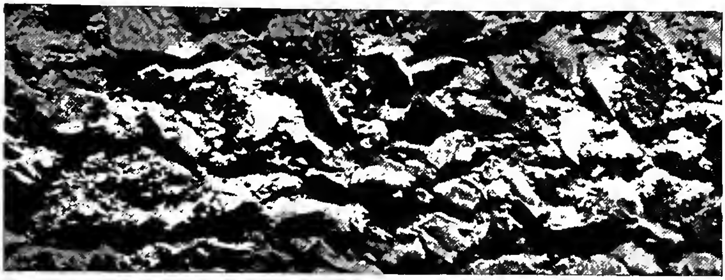


FIG. 33

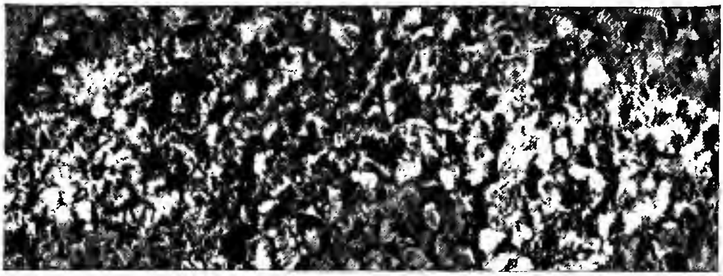


FIG. 34

REINFORCED CONCRETE

101. General Explanations. — Reinforced-concrete structures are structures built of concrete in which steel has been embedded to add tensile strength to the concrete. The amount of metal used is generally small in proportion to the amount of concrete. In this type of construction *the steel and* *the concrete are so placed and combined that either, if left alone, would sustain but a small fraction of the load which they will carry when combined.* There are other forms of construction in which concrete and steel are used in combination but which are not of reinforced-concrete construction. In one form the steel carries all or practically all the load, the concrete serving merely as a protective coating. In another form the concrete carries all or nearly all the load, and the steel is used to tie parts of the structure together.

102. Uses of Reinforced Concrete in Building. Reinforced concrete is well adapted for use in the construction of walls, beams, girders, columns, floor slabs, or other parts of the structure which carry the loads. It is also an economical material, and entire buildings are built of it, such as warehouses and factories where appearance is a secondary consideration. It is also employed in constructing buildings that are artistic, but such work is not particularly economical since these results can be obtained only by the use of expensive materials, expert workmanship, and with the greatest care in the construction. The use of reinforced concrete for artistic construction is nevertheless rapidly increasing, especially in the erection of high-class residences, schools, etc.

STRENGTH OF CONCRETE

103. In considering the strength of concrete, the forces acting in the various parts of a building that are constructed of concrete should be understood. These forces are known as *tension, compression,* and *shear.*

Tension is a force which tends to pull a body apart. It is resisted by the *tensile strength* of the material. *Compression* is a force that tends to crush or push together a body or mass of material. This is resisted by the *compressive strength* of the material. *Shear* is produced by two forces acting in opposite directions in a manner similar to the two blades of a pair of shears. These forces tend to push one portion of a body past another part, thus dividing it. The forces mentioned are generally the result of direct loads applied to the various columns, piers, girders, and beams.

104. In the case of steel, the compressive and tensile strengths are approximately equal. In concrete, the compressive strength is from six to ten times as great as its tensile strength. In other words, it requires from six to ten times the load or force to destroy it by compression that it does to break it by tension. The resistance of concrete to shear is also quite small.

105. The compressive strength of concrete is therefore its most important one and this can be determined by testing cubical or cylindrical specimens of the concrete. After these have been made and allowed to harden for a certain time, such as 28 days, they are tested in suitable machines by crushing or compression. The load or force required to crush each is noted and is then divided by the horizontal cross-section of the specimen in square inches and the number of pounds per square inch required to crush it is obtained. The crushing strength increases with the age of the concrete and with the increase in the proportion of cement used in making it.

TABLE II

TABLE OF CRUSHING STRENGTH OF DIFFERENT MIXTURES OF CONCRETE, IN POUNDS PER SQUARE INCH

Aggregates	1 : 1 : 2	1 : 1½ : 3	1 : 2 : 4	1 : 2½ : 5	1 : 3 : 6
Granite, trap rock	3,300	2,800	2,200	1,800	1,400
Gravel, hard limestone and hard sandstone	3,000	2,500	2,000	1,600	1,300
Soft limestone and sandstone.	2,200	1,800	1,500	1,200	1,000
Cinders	800	700	600	500	400

106. In Table II the average crushing strength of various mixtures of concrete, in pounds per square inch, is given. The specimens tested were cylinders 8 inches in diameter and 16 inches long, and the age of the concrete was 28 days.

The figures here given were determined by the Joint Committee appointed by the American Society of Civil Engineers, the American Society for Testing Materials, the American Railway Engineering Association, the Portland Cement Association, and the American Concrete Institute. This committee recommends that concrete used in construction should not be loaded more than a certain fraction of the ultimate, or crushing, strength indicated in the table. Building codes, in general, do not make the distinction between the various coarse aggregates that are given in this table nor do they give the ultimate crushing strength of the concrete. Instead, however, they give the load that is permitted, called the *safe load* per square inch, for concrete formed with different proportions of ingredients. For example, the New York Building Code contains the following:

CONCRETE IN COMPRESSION	SAFE LOAD PER SQUARE INCH
Concrete, Portland cement, 1 : 2 : 4	500 lb.
Concrete, Portland cement, 1 : 2½ : 5	400 lb.

From this it will be noted that the 500-pound load is 22.7 per cent. of the crushing load given in Table II for trap-rock concrete having the same proportions of ingredients; and the 400-pound load is 22.2 per cent. of the crushing strength of concrete of similar proportions and like material. Thus, in practice, the safe load for concrete is taken as a little more than one-fifth of the crushing strength shown in 28-day tests.

107. Advantages of Reinforced Concrete.—Reinforced concrete buildings, when properly designed and built, are very strong. They can be erected at a reasonable first cost and the cost for upkeep is low. They are therefore looked upon with favor in purely commercial enterprises.

Buildings formed of this construction are less affected by vibrations and shocks than some other types, because they are so firmly knit together that they are not easily disturbed. They are particularly adapted to regions subjected to earthquake. They have the additional advantage of being fireproof, dampproof, and vermin-proof, thus protecting their contents from injury by fire, water, or rodents.

THEORY OF REINFORCED-CONCRETE CONSTRUCTION

108. Classes of Members.—Reinforced-concrete buildings are formed of walls, columns, piers, girders, beams, and slabs. These members may be grouped into two classes, namely, *columns* and *beams*. Under the heading *columns* may be placed vertical supports such as columns, piers, and walls, and under *beams* all horizontal members such as girders, beams, and floor and roof slabs.

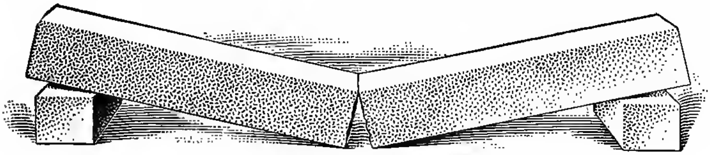


FIG. 35

The principles used in designing these two classes of members are very different, and will be merely illustrated in this Section, but will be more fully discussed in the Sections *Design of Columns* and *Design of Beams*.

109. Beams.—All the horizontal members of a structure, such as girders, beams, and floor slabs, are virtually beams. The stresses acting in loaded beams can be shown by experiment. Thus, if, as shown in Fig. 35, a concrete beam, without steel reinforcement is loaded until it fails, or breaks, it will in all probability break as shown in this figure. The lower portion will be pulled apart due to limited tensile strength of concrete.

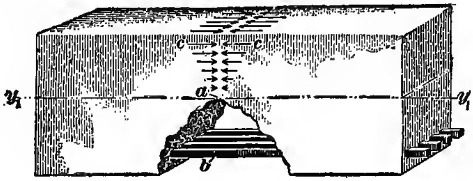


FIG. 36

110. Now if a sufficient number of steel rods are introduced near the lower surface of the beam, as shown at *b* in Fig. 36, the tendency to pull apart in its lower portion, when the beam is loaded, will be overcome. The effect of a load on a beam is to produce compression in the upper portion of the beam as indicated by the arrows *c*, and tension in the lower portion, which is neutralized by the steel rods. The concrete has considerable compressive strength and resists strongly any tendency to crush it. In a well-designed beam, the crushing strength of the beam above the line $y_1 y_1$ will be balanced by the tensile strength of the steel below the same line.

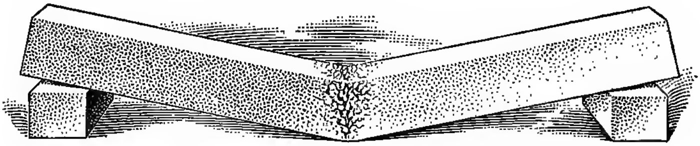


FIG. 37

111. If there is more tensile strength provided in the steel reinforcement than there is crushing strength in the concrete, and the beam is loaded until it breaks, it will fail by crushing at the top, as illustrated in Fig. 37. It will require, however, a much greater load to break the beam in this case than in the case shown in Fig. 35, thus demonstrating that the reinforcement adds much to the strength of the beam.

The designing of reinforced-concrete beams consists of supplying the proper proportion of reinforcing steel and concrete so that under a maximum load, the steel will not fail by tension before the concrete fails by compression, and vice versa.

112. When the concrete and the steel are under about the same stress, the beam, if heavily loaded, will sometimes stretch the steel excessively and the concrete will develop small cracks such as shown at *a* in Fig. 38.

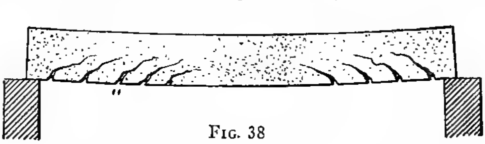


FIG. 38

113. Columns.—In columns, reinforcement is not absolutely necessary, as concrete is strong in compression. It is, nevertheless, good practice to use reinforcement, because the steel makes the column safer to use and also increases its carrying capacity. A smaller reinforced column will therefore do the work of a larger one not reinforced and will occupy less space. This reduction in size is due to the fact that the strength of the steel rods encased in concrete in resisting compression is very great. Even a small amount of steel thus embedded will support a considerable load and permit of a reduction in the concrete area required. The arrangement of reinforcement in columns will be shown later on.

114. Design of Reinforced-Concrete Buildings. The complete computations required for the design of reinforced-concrete beams and columns are complicated and the architect therefore usually entrusts this part of the work to engineers who have made a specialty of reinforced-concrete work. It is, nevertheless, important for the architect to know the principles involved in the design so that he can arrange the architectural features of a building harmoniously with the engineering features, and also so that he can tell in the field whether or not the principles of good construction are faithfully followed. For this reason, the following articles will be devoted to a brief description of the best types of reinforced-concrete building construction and the principles upon which these types are based.

In making the preliminary plans, the architect should make provision for columns having a somewhat larger area than for steel columns that carry equal loads. He should also provide in the height of the stories for the greater depth of beams and girders that are required in reinforced-concrete construction.

REINFORCEMENT

REINFORCING MATERIALS

115. Quality of Steel.—Steel selected for reinforced concrete should be of a quality that is suitable for this purpose. It may be advisable in small structures to obtain the steel from a local stock, even though the quality of the steel is not the best; for large structures, however, the quality of steel desired is usually specified and the order is filled at the rolling mill, or it may be taken from stock that has been proved by tests to conform to the specified requirements.

116. The specifications generally followed in describing reinforcing steel are those of the American Society for Testing Materials, which recognizes two different kinds of steel, namely, *billet steel* and *rerolled steel.* **Billet steel** is made from new billets or blocks which are rolled out to the required shape. There are three varieties of this steel, known as *structural, intermediate,* and *hard* steel. **Rerolled steel** is made from old railroad rails that are split and heated and passed through rolls in order to form them into the proper shape. There is only one grade of rerolled steel and it has properties similar to those of the hard grade of billet steel. Owing to its brittleness, which is especially pronounced in frosty weather, hard steel and rerolled steel are adapted only for structures that are not subject to shocks or vibrations and in which the rods or bars do not require much bending.

Specifications for reinforcing steel frequently require that samples be taken from the various shipments of steel, after they have been received at the building site, and tested to prove that the steel is of the quality required. This is done by employes of a testing laboratory.

117. Allowable Stress in Steel.—Steel is considered as being able to sustain safely a tensile force of 16,000 pounds per square inch. The safe compressive strength of steel is taken to be 10,000 pounds per square inch.

This compressive strength of steel is about 15 times the safe compressive strength of concrete, which is considered to be from 650 to 750 pounds per square inch.

118. Forms of Reinforcement.—Steel reinforcement for concrete construction may be in the form of loose rods or bars, rods or bars that have been secured together into shapes known as *units,* sheet metal which has been expanded into what is known as *expanded metal,* and wires that have been woven or welded together to form what is known as a *fabric.*

The loose rods or bars may be used as a reinforcement in any of the structural parts of the building. The units are used only in the beams, girders, and column construction; and the expanded metal, perforated metal, and fabrics, in the wall and floor construction. The forms of these reinforcing members are described later on in this Section.

BARS AND RODS

119. Forms of Bars.—Steel bars and rods for reinforcing concrete may be either plain or deformed. Plain bars are round or square, as shown in Fig. 39. Deformed bars are twisted or provided with projections and depressions for the purpose of increasing the adhesion of the concrete to the bar. Deformed bars are illustrated in Figs. 40, 41, and 42. The terms bar and rod are used interchangeably and may apply to round or square bars, either plain or deformed.

Fig. 39

Many buildings in this country have been built with plain bars and practically all work done in foreign countries has been erected with plain bars only. Most American engineers, however, prefer the deformed

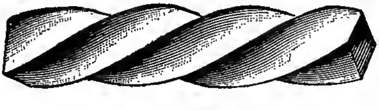


Fig. 40

bars as offering additional safety at a very small increase in cost.

120. Adhesion Between Concrete and Steel.—A steel bar embedded in concrete offers considerable resistance to being pulled out. This resistance is due to the adhesion between the concrete and the bar. The adhesion of the concrete to steel bars is naturally increased by deforming the bar, and a smaller deformed bar will do more work than a larger plain bar.

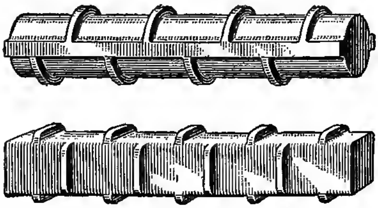


Fig. 41

121. To test the adhesion between steel bars and concrete, specimens such as shown in Fig. 43 are prepared, consisting of a block of concrete in which a steel bar of the kind to be tested is embedded, with one end projecting as shown. The test consists in pulling the bar out of the concrete block and noting the force required to do so. If, in testing different kinds of bars, two bars of equal diameters and equal lengths of embedment show different resistances against efforts to pull them out, the conclusion is naturally drawn that the bar requiring the greatest pull adheres best to the concrete and is therefore the one to be preferred in practice.

Many tests of the kind described have been made and have showed that the adhesion is greatest when a rich mixture of concrete is used; that the adhesion is greatly increased when care is used in preparing and storing the specimens and especially when the concrete is kept moist during its hardening period so as to furnish sufficient water for the cement to set properly; and that it is very important that the bars be embedded in large blocks. Therefore, in actual construction the concrete should be properly proportioned, carefully placed, and kept moist until hard, in order to develop the greatest adhesion; and also

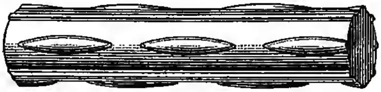


Fig. 42

the bars must be kept away from the immediate surface of the concrete member in which they are embedded.

122. Deformed Bars.—Of the many deformed bars obtainable in the market, only a few will be mentioned as typical of various designs.

The **Ransome bar,** Fig. 40, is made by twisting a plain square bar in a cold state. The sliding resistance of the bar is increased by the spiral ridges along the surface of the bar. These bars are made of soft steel, are easily bent on the job, and make good reinforcement.

123. Hot-twisted bars are rerolled bars twisted in a hot state. They are usually very hard and very brittle and should not be used without careful testing to insure the quality. They may be recognized by being covered by so-called *mill scale,* which is a metallic coating formed in scales upon the surface of all bars when they leave the mill. This mill scale drops off the cold-twisted bars in the twisting process.

124. Corrugated bars are shown in Fig. 41. These bars are formed with projections on all sides which extend into the surrounding concrete and obtain a firm grip.

125. Havemeyer bars are made round, square, and **I** beam in shape. They have longitudinally extending fins or projections giving the bar a wavy outline in profile. In Fig. 42 is shown a round bar of this design.

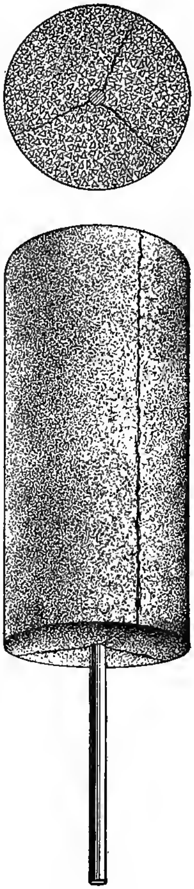


Fig. 43

126. Trussed bars, also known as *Kahn bars,* are made from bars having at two opposite sides flat extensions as shown in Fig. 44 at *a*. These extensions are sheared along part of their length so as to separate them from the body of the bar for considerable lengths, only short spaces of connection being left at intervals. The sheared portions *b* are bent to form prongs or projecting parts as indicated in Fig. 45. These projecting parts serve to increase the adhesion of the bar to the concrete, and also act as reinforcement of the concrete, to resist the action of shear.

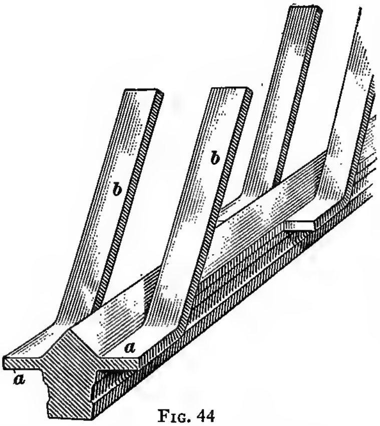


Fig. 44

There are many other kinds of deformed bars on the market all of which possess some particular point in their favor.

127. Units.—Bars intended for the reinforcement of beams and girders are sometimes assembled at the mill in the form of frames called **units.** The advantage of forming the reinforcement into a unit at the mill is that the various bars are properly placed and held in position more accurately than they might be if built at the building. The bars are fastened together and when set in the form they are all in the proper relation to one another and in such a position that they will be most effective in resisting the various stresses in the beam or girder. An example of a unit designed for use in a girder is shown in Fig. 46.

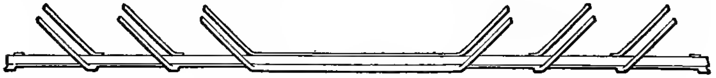


Fig. 45

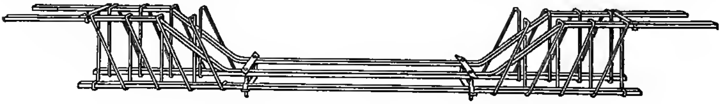


Fig. 46

128. Spirals.—For columns, reinforcement in the form of spirals or hoops such as shown in Fig. 47 (*a*) is also made at the mill in a *unit*, consisting of the spiral stiffened by the vertical members *a*.

129. Both the units for girders and the spirals for columns are frequently made so that they can be folded flat for convenience in shipping. When they are to be used in the building they are expanded to their proper shape and set in the forms. A collapsible spiral reinforcement unit for a column is shown in Fig. 47. In (*a*) is the expanded unit, in (*b*) is a view of the unit collapsed, and in (*c*), a side view of the collapsed unit.

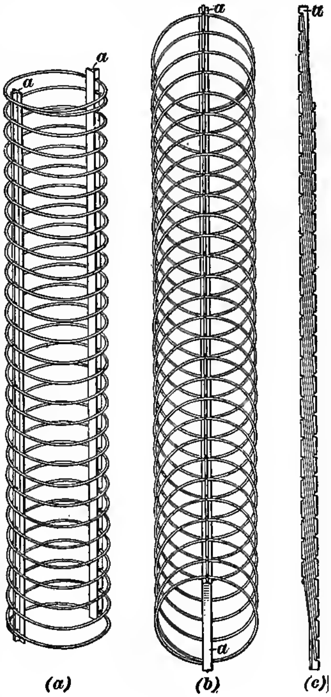


Fig. 47

EXPANDED METAL

130. The form of sheet-metal reinforcement known as **expanded metal** is shown in Fig. 48. This material is made in sheets of short lengths that are easily put in place. They must be lapped, however, wherever they meet. The meshes, or diamonds, are formed in different sizes and the metal is made in different thicknesses according to the purpose for which the reinforcement is to be used. The 3″×8″ mesh, or opening, is commonly used in reinforcing floors in buildings and the 6″×12″ mesh is used for sidewalks. The manufacturers' catalogs give the various thicknesses, mesh sizes, and strengths of the different patterns of expanded metal when used for different floor spans and with various mixtures of concrete.

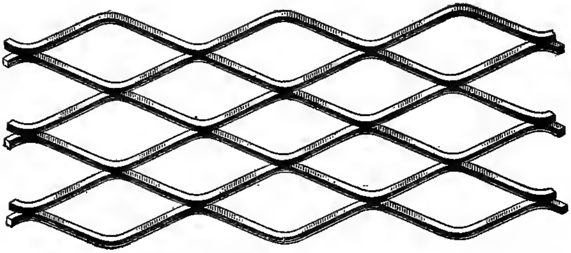


Fig. 48

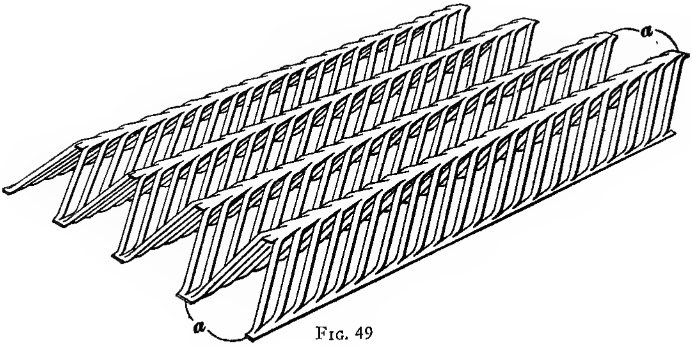


Fig. 49

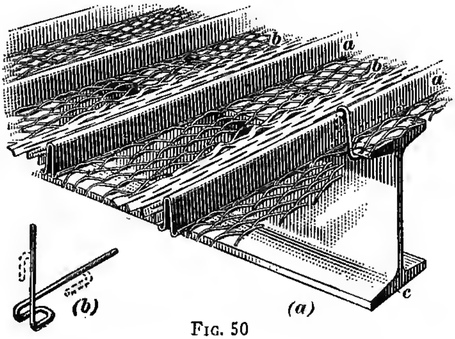


Fig. 50

In laying out expanded-metal reinforcement, the long dimension of the diamonds should always be placed in the direction of the shortest span. The ends of the sheets should be lapped the length of one diamond and the sides the width of one diamond.

131. A form of expanded metal that is used for reinforcing thin slabs of concrete, such as are used for roofs and very light floors, is shown in Fig. 49. This consists of what is called herring-bone lath, bent at the ribs, thus making a sheet that is quite stiff. This product is known as *Trussit*.

132. There are many other forms of expanded metal and metal lath on the market; many of these can be used in concrete work without forms, the metal being stiffened by ribs so that it will support the weight of a light concrete slab. Such materials are known as *self-centering*, because no centers, or forms, are required. In this form of reinforcement a sufficient amount of the concrete passes through the meshes to secure the necessary adhesion between the steel and the concrete. By this bonding of the materials, the steel provides the necessary tensile

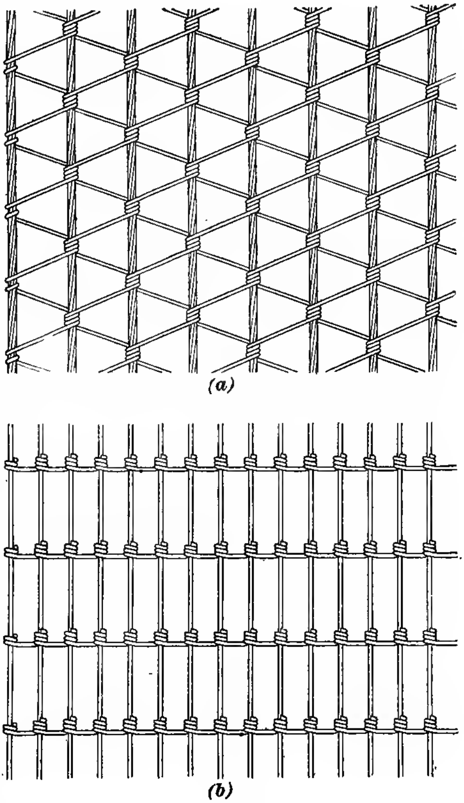


FIG. 51

strength to resist the stresses due to the loads in the structure.

One form of self-centering reinforcement is shown in Fig. 50. It has standing ribs *a*, and between them are expanded-metal panels *b*. This lath is shown supported by steel beams *c*. In (*b*) is shown the form of the clip with which the sheets are fastened to the beams to prevent displacement during the concreting.

WIRE FABRICS

133. For reinforcement of slabs, what are called *wire fabrics* are frequently used. These are made by weaving or welding together wires or rods into meshes having rectangular or triangular shapes.

A woven-wire fabric having a triangular mesh is shown in Fig. 51 (*a*). The reinforcing parts of the fabric are the heavy members, which consist of several small wires twisted together in the form of cables.

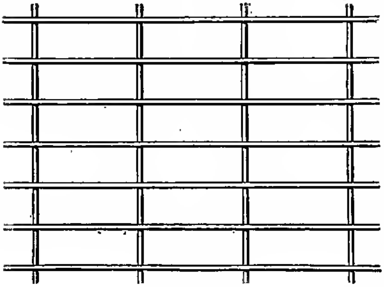


FIG. 52

A fabric of similar design is also made by using heavy wires or round rods instead of cables for the main reinforcing parts. These heavy strands or rods must be placed in the direction of the span, and the lighter wires serve as secondary reinforcement.

In Fig. 51 (*b*) is shown a fabric formed of wires that have been woven together into rectangular-shaped meshes.

In Fig. 52 is shown a rectangular mesh formed by welding the wires together. By this means of fastening, a solid and substantial union between the wires is obtained. Meshes of this form are made in different sizes, and fabrics are formed of different sizes of wires to meet the requirements of the loads that are to be carried.

Woven and welded wire fabrics are made in long lengths and are received at the building in rolls. They waste less material than sheets of expanded metal, as a slight lapping is suffi-

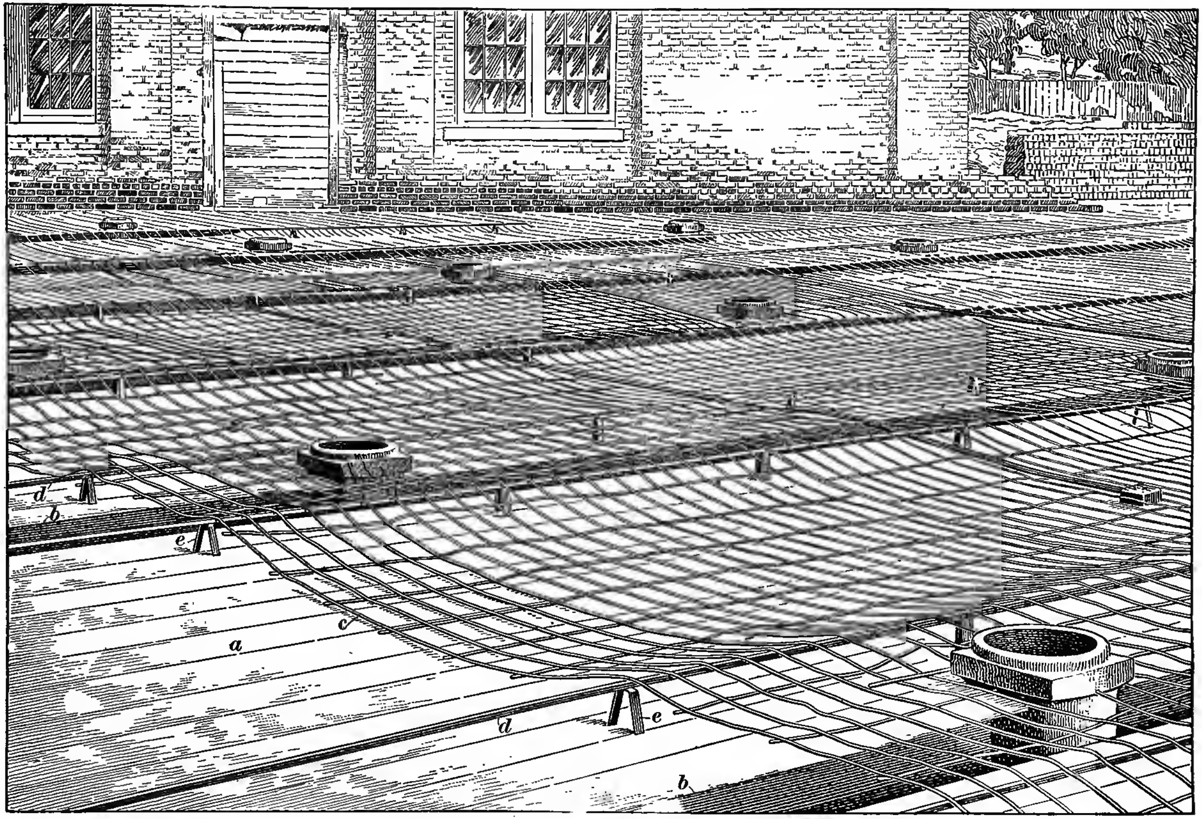


Fig. 53

cient to bond the reinforcement together, and fewer lappings will be required.

134. Fig. 53 illustrates the practical application of welded-wire rectangular-mesh fabric to a reinforced-concrete floor. The form work *a* extends between the beams *b*. The fabric *c*, which extends with the heavy wires spanning from beam to beam, is raised over the beams and droops between them nearly to the bottom of the slab, or nearly to the surface of the forms. This is accomplished by supporting the fabric upon rods *d*, one on each side of each beam. These rods extend parallel with the beams, and are held up by small iron chairs *e* fastened to the forms. When the concrete has been placed and has hardened, the forms are removed, leaving the chairs and rods in place within the concrete.

APPLICATION OF REINFORCEMENT

COLUMNS

135. Columns are reinforced either *vertically* or *laterally*, or both together. In the vertically reinforced columns the reinforcement is placed as in Fig. 54, where *a* is the concrete and *b* the reinforcement. The rods are placed as near as possible to the outer faces of column, with only enough concrete outside of the reinforcement to afford fire protection. The rods are held in the proper relative position by means of wire ties *c*, placed from 6 inches to 18 inches apart.

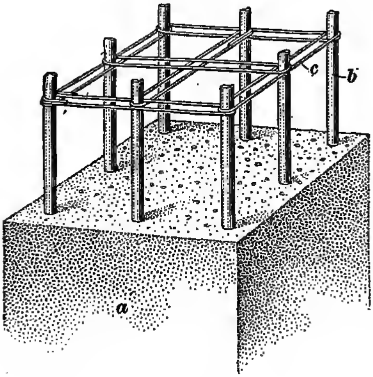
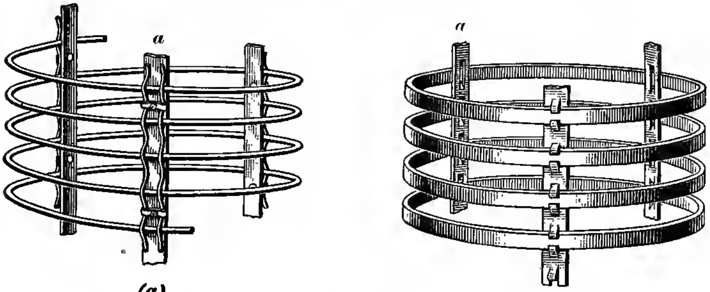


FIG. 54

In *laterally reinforced* columns, the hoop reinforcement, such as is illustrated in Fig. 55, is employed. The hoop reinforcement may be in spiral form as in (*a*) or may consist of a series of independent bands as in (*b*). Both the spirals and the hoops are held at a fixed distance apart by means of separators, or spacers, *a*.



(a) (b)

Fig. 55

136. Effect of Hoops.—The strengthening action of column hoops will be understood from Fig. 56. If a vertically reinforced-concrete column be loaded until it breaks, that is, until the concrete crushes, it will take the appearance indicated, the vertical rods *a* buckling between the ties *b*. But if the ties are closely spaced, as in a hooped column, the concrete cannot escape sidewise, being held in by the hoops. The hoops furnish a jacket for the concrete and prevent it from escaping sidewise, thus increasing the safety of the column. All hooping of columns should have an outside covering of concrete 2 inches thick for protection from fire and corrosion.

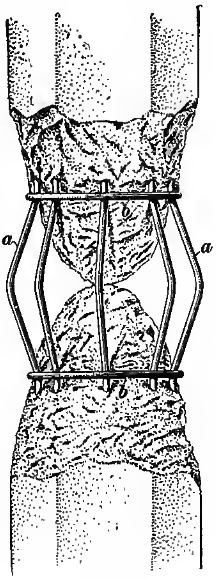


Fig. 56

The hooped form of reinforcement is considered stronger than the vertical form, for the same amount of metal used. The spacers in the hooped reinforcement have a certain value as straight reinforcement and in some cases more straight reinforcement is added to the hooped reinforcement to give more strength to the column.

As was shown in Fig. 47, this hoop reinforcement is made in units and can be folded together when shipped and opened up into the proper shape when set in position.

BEAMS AND FLOOR SLABS

137. Since steel is used principally to resist the tension stresses in beams, and since these tension stresses are located at the bottom of the beam, the steel must be placed at the lower side of all beamlike structures. The depth of a beam is measured from the top of the concrete to the center of the steel at the bottom, and the deeper a beam is, the greater is its strength. It is therefore desirable to have the steel as close to the bottom of the beam as possible in order to have a beam of the greatest possible depth and therefore of the greatest possible strength. There is, however, a limit beyond which it is not advisable that the steel approach the bottom of the beam. This depth is determined by the following considerations:

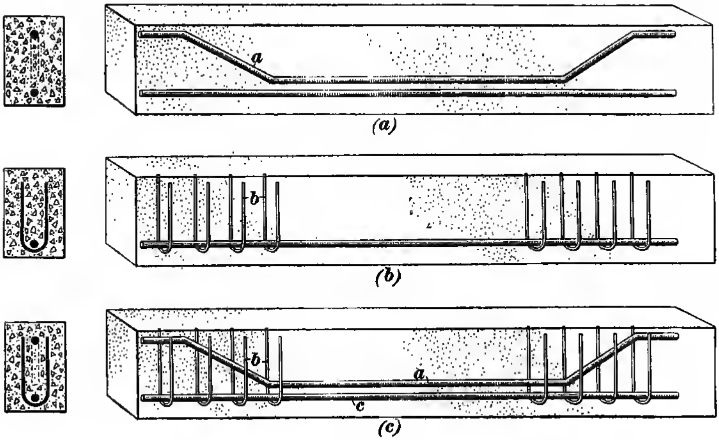
1. *Adhesion must be developed* between concrete and steel, and this is possible only when a proper amount of concrete surrounds the steel. If no adhesion were present, the steel and concrete would not act in unison and assist one another, and the beam would fail.

2. *The steel must be protected against fire.* If the heat should penetrate the concrete far enough to soften the steel, the beam would fail.

3. *The steel must be protected against corrosion.* If moisture and air should reach the steel and cause it to rust, the steel would in time become eaten up and the beam would fail.

For these reasons, concrete must surround all the reinforcement. It is customary to cover the steel of beams with 1½ inches, and the steel of girders with 2 inches, of concrete. Where the reinforced-concrete work is especially exposed, as when near water, and especially near salt water, these dimensions should be increased.

138. Stirrups.—While it may not be easy to understand why stirrup bars are required in beams, experience shows that even though a beam contains sufficient steel in the main tension rods already referred to, it may fail by small cracks opening up in the manner indicated in Fig. 38. These small cracks may be prevented by the addition of the reinforcement indicated in Fig. 57, the additional reinforcement being so placed as to extend into the body of the beam, as in (*a*), in



(a)

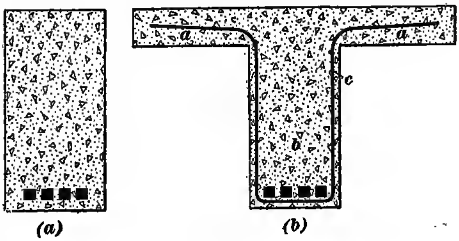
(b)

(c)

Fig. 57

the shape of bent rods *a*, or, as in (*b*), in the shape of light auxiliary rods *b* encircling at their bottoms the main tension rods. These auxiliary rods because of their shape are known as *stirrups* or **U** *bars*. In the best types of construction, both the straight rods and the stirrups are combined as in (*c*), where straight bars *c* and bent bars *a* extend from end to end, in conjunction with **U** bars *b* as shown.

139. Forms of Concrete Beams.—There are two kinds of reinforced-concrete beams; namely, *rectangular beams*, as shown in Fig. 58 (*a*), and **T** *beams*, as shown in (*b*). It has already been explained that a plain-concrete beam, such as shown in (*a*), may break by its tensile resistance at the bottom being overcome. By the addition of steel reinforcement to strengthen the bottom, a reinforced-concrete beam is obtained that will



(a) (b)

Fig. 58

break only under greater loads and by compression in the top. Since this beam has its weakest point at the top, it is desirable to strengthen the top and thereby the entire beam. This may best be done by increasing the concrete at the top. The concrete is increased, as in (*b*), by adding a flange *a* to each side of the rectangular web *b*, which is usually part of the floor slab between the beams. A beam so constructed is much stronger than the rectangular beam shown in (*a*) and is known as a **T** *beam*.

140. Construction of Concrete Beams.—The **T** beam is a feature of reinforced-concrete building construction which makes for great economy. A reinforced-concrete floor consists usually of beams and of floor *slabs* between the beams. It has been found entirely feasible to unite the floor slab and the beams so that each and every beam becomes a **T** beam, and the flanges of these **T** beams are obtained at no expense whatever, since the slab must be made in any event, to form the floor. The only requirement is that the flange shall be well tied to the web, as otherwise they cannot be counted upon to act in unison, that is, the slab will not act as a flange unless well tied to the web. This result is obtained by two expedients, namely, by extending the stirrups *c* so that they project well into the slab *a*, and by so placing the concrete that there is no plane of cleavage or separation between slab and web of the beam. In other words, the concrete of slab and beam is poured in one operation, so as to form one solid mass after hardening. Concrete so poured as to form one mass is called **monolithic** concrete, the meaning of the word monolithic being *one stone*.

EXAMPLES OF REINFORCED-CONCRETE CONSTRUCTION

141. Typical Exterior.—The typical reinforced-concrete building in course of construction, illustrated in perspective in Fig. 59, combines the several elements already described. This building is a warehouse of the type of construction known as skeleton construction. In this construction the exterior con-

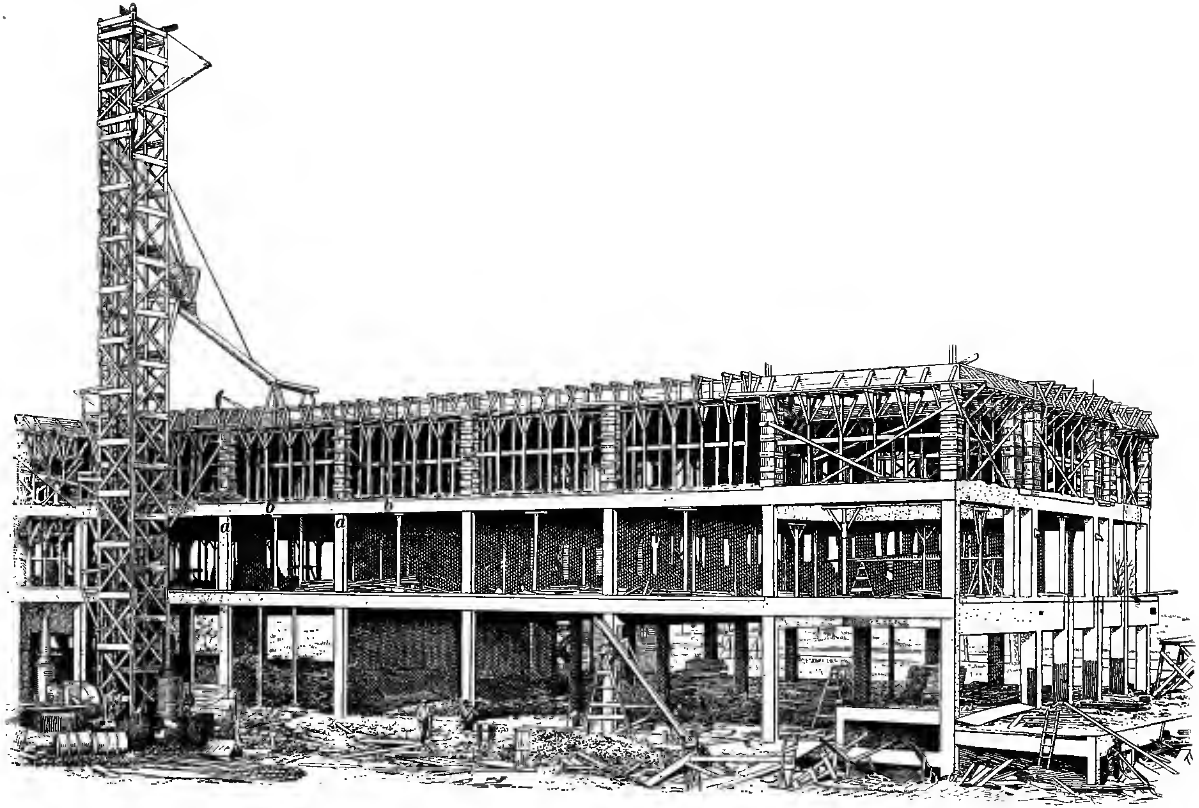


FIG. 59

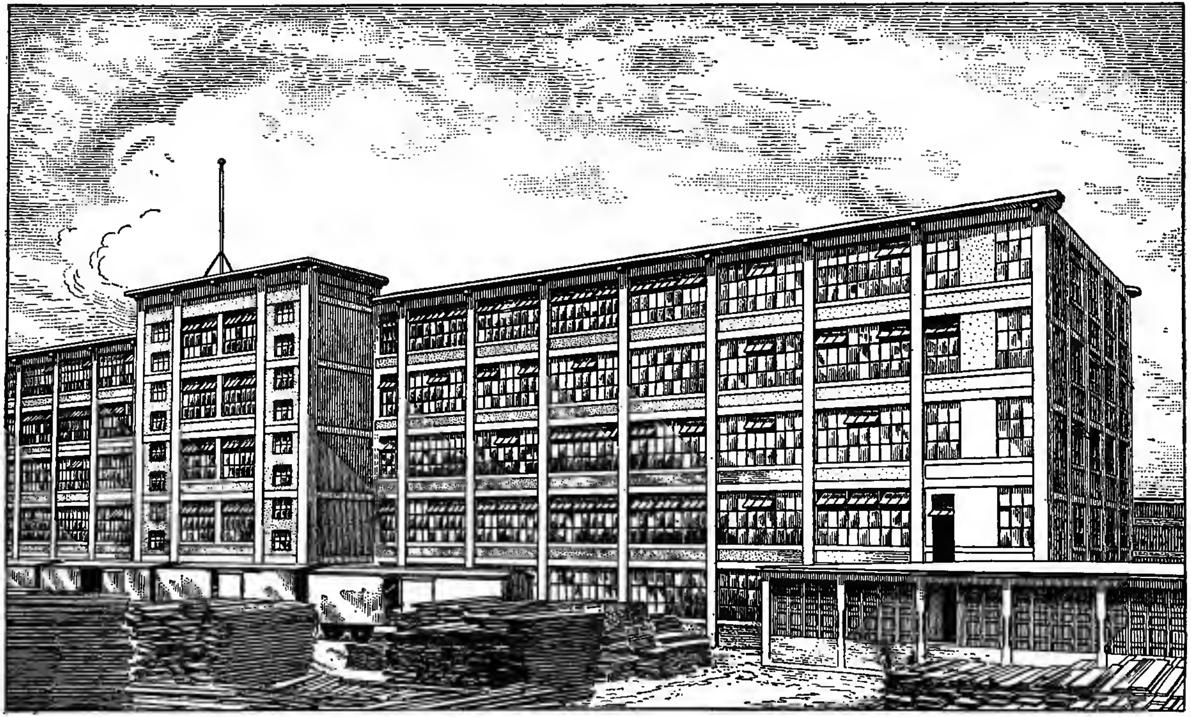


Fig. 60

sists entirely of vertical piers or columns *a* and horizontal beams and girders *b*. The openings will subsequently be filled with walls up to the window-sill levels, and with sash. The beams *b* are made strong enough to support these fillings as well as a portion of the floor loads. The building when finished will present a neat and useful appearance but will not be a particularly pleasing structure from an architectural point of view.

142. In Fig. 60 is shown a completed building similar in construction to the one in Fig. 59. The same pier and girder construction will be noted, but the spaces between the piers and girders have been filled up. In most of these spaces the filling consists of a brick wall from the girder up to the window sill and a glass enclosure above. Some of the spaces, as on the side of the projecting wing, are filled entirely with brickwork. A building of this character is for utilitarian purposes entirely, space and light being the main objects sought for.

143. **A typical interior construction** is shown in perspective in Fig. 61 (*a*) and in sectional elevation in (*b*). This illustration shows a reinforced-concrete column which supports reinforced-concrete beams and girders. Over the beams and girders extends a floor of reinforced concrete which is monolithic with the beams and girders and is called the *slab*. The concrete is indicated partly broken away in (*a*) to show more clearly the main tension rods *a* and *b* of a beam, rod *a* being straight and rod *b* bent. These rods are encircled by stirrups *d*, and other stirrups are similarly disposed in the concrete of the main girder. The ends of the reinforcing rods of the main girder can be seen, and the ends of the reinforcement of the slab are shown projecting beyond the edge of the slab. The sectional elevation (*b*) shows more clearly the reinforcement of the main girders over the column, and especially how the bent rods of the girder are continued into the adjacent span as at *c*. The purpose of extending the rods *c* into the adjacent span is twofold: first, to tie the several parts of the building together, and second, to resist certain tension stresses which experience shows exist in the girders over the tops of the columns. A similar arrangement is used in the beams where these cross over the tops of the girders. The general system of reinforcement in floors of the type here shown is therefore to have, in all parts, certain straight rods and certain bent rods, the straight rods being near the bottom of the member throughout their length, and the bent rods being near the bottom of the member at the center of the span, and raised over the supports at the ends of the span. A building constructed on the principle shown in Fig. 61 is said to be of a *slab-and-beam construction.*

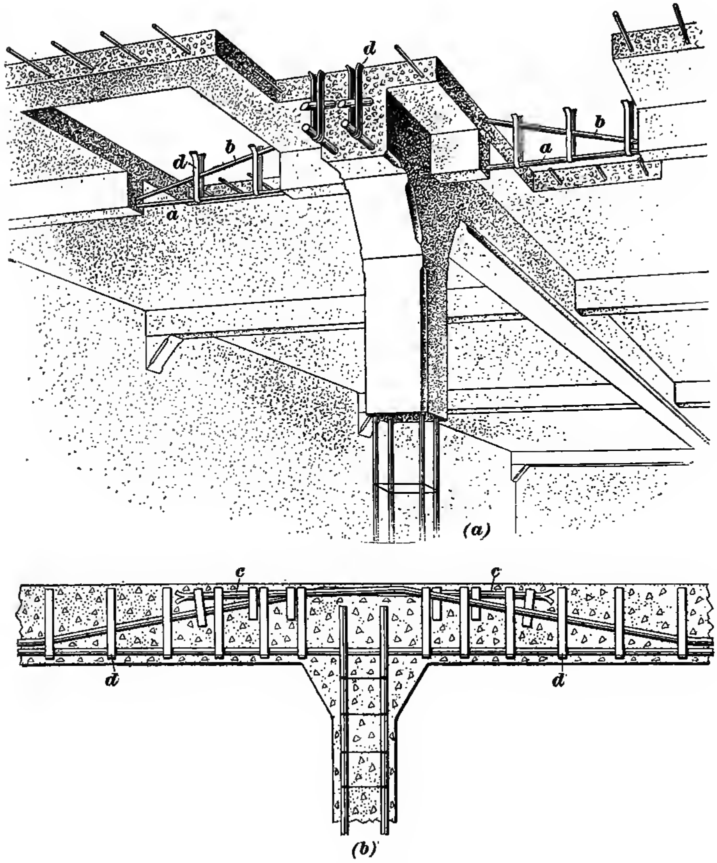


FIG. 61

144. Tile-Concrete Floors.—While a great many buildings of the slab-and-beam type have been erected, the forms needed for their construction are complicated, and the finished ceilings are broken up by the beams and girders. The construction may be somewhat simplified by using longer spans so as to dispense with some of the beams. But, the longer the span, the thicker the slab must be, and consequently the more heavy and expensive.

In order to lighten the slabs and thereby cheapen the construction, the floor system shown in Fig. 62 is used. In this the slab consists of a number of small beams separated by hollow tiles, with a thin concrete slab extending over the tops of the beams and the tiles. Floors of this kind, known as *combination tile-concrete floors,* are very useful where no heavy loads are to be carried.

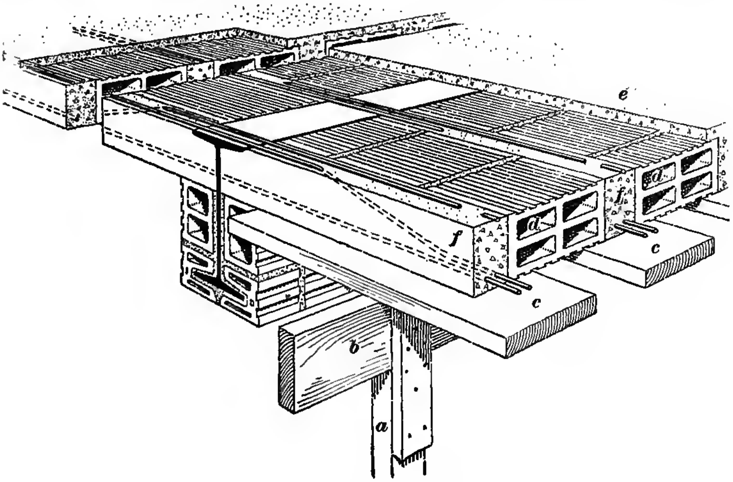


FIG. 62

145. Flat-Slab Floors.—In the so-called *flat-slab floors* the beams and girders are dispensed with altogether. The floor consists merely of a flat slab which, as indicated in Fig. 63, rests directly upon the columns. This type of floor is also often called a *mushroom* floor because the columns are generally flared at the top and suggest the appearance of mush-

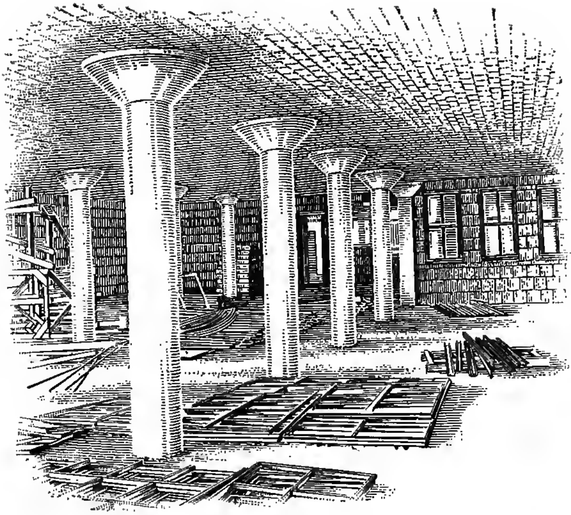


FIG. 63

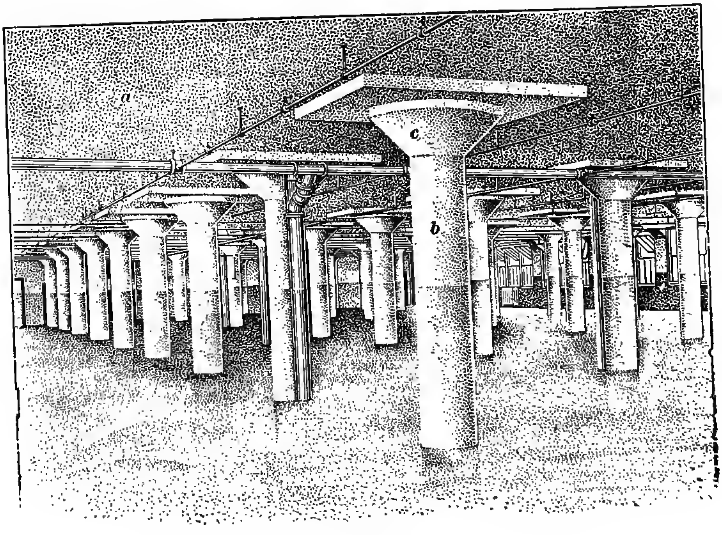


FIG. 64

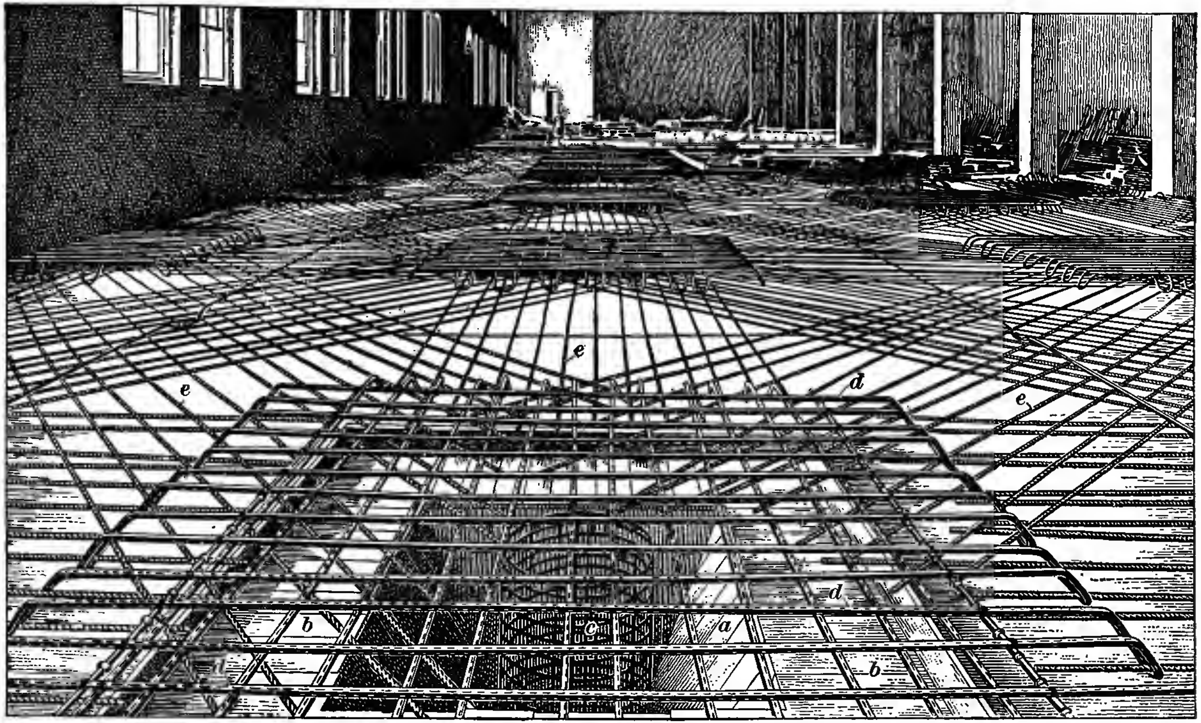


Fig. 65

rooms. Often the cap is surrounded by a thickened portion of the floor called a *drop panel,* as shown in Fig. 64. Drop panels are most common in heavy construction, such as is used in warehouses. The general arrangement of the reinforcement is shown in Fig. 65. The form for the spread cap of the column below is shown at *a* and the form for the drop panel at *b*. Hooped reinforcement for the column *c* and heavy reinforcement *d* on the top of the column are also illustrated. The slab reinforcement *e,* which consists of lighter rods, extends diagonally and also in direct belts, from column to column. As is usually the case in reinforced-concrete construction, the reinforcement is near the bottom midway between supports and raised to near the top of the slab over the supports, so that the steel rods combine to form a so-called *mat* over each column.

FORMS FOR REINFORCED-CONCRETE STRUCTURES

146. General Features of Forms.—There are many different ways in which forms for reinforced-concrete structures may be built. The method used is generally dictated by the peculiar requirements of each case or the preference of the contractor.

Forms for reinforced-concrete structures often are of the same kind as those used for structures of plain concrete; as an example, the forms illustrated in Figs. 25 to 28 could be used equally well for construction of reinforced concrete.

147. Forms are expensive items in the construction of a reinforced-concrete building and it is therefore important that they be so designed and assembled that they can be easily removed and used many times without alteration. To facilitate this repeated use, the architect or engineer should design all floors so that the beams and girders are of the same size and location on as many floors as possible. An example of such design is shown in Fig. 59, where the same forms are being used on the third story that were used to cast the similiar parts of the lower stories.

It is true that beams and girders must be made stronger where heavier loads are to be carried and consequently it is not always feasible to adhere to one layout for all of the floors, but in many cases the forms may remain the same size, and the strength of the beam or girder be increased or decreased by an adjustment in the amount of the steel reinforcement that is used.

148. Forms for Columns and Piers. — Concrete columns are usually cast either in a round, octagonal, or rectangular shape. The round or octagonal column is generally used where the floors are of the flat-slab construction, and hooped reinforcement is used in them.

Rectangular piers or columns are frequently used to support floors of the beam-and-slab type, and are generally used to support the outside wall construction, as the projecting corners are less objectionable along the wall than on the independent columns in the interior parts of the building.

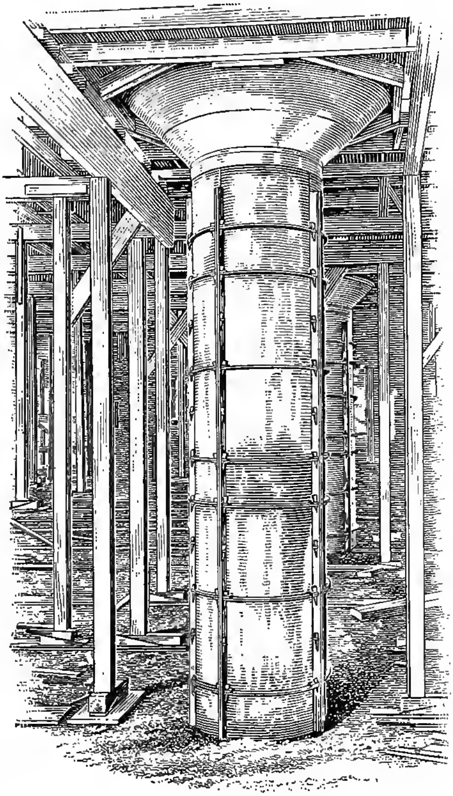


FIG. 66

149. Forms for Round Columns.—The forms for round columns are usually composed of light steel plates that have been previously bent to form the curves required. These plates are held together by means of bands and vertical bars as shown in Fig. 66. The bands and bars are fastened together by means of steel wedges.

Round columns that support a flat-slab floor construction are usually formed with a circular cap as shown in the illustration. The form for this cap is also made of sheet metal, the top portion having a flange that is fastened to the wooden form of the floor construction and the lower portion having a collar that fits over the column form.

Forms of this type are usually patented and are rented from the manufacturer for the period of time required to complete the job.

By the use of metal forms as described, a concrete column is cast which requires very little if any refinishing, as the surface is smooth and free from defects such as are common when wooden forms are used.

150. Forms for Square Columns.—A wooden form for a square column, or pier, which carries a beam-and-slab floor construction is shown in Fig. 67. The sides of this form are composed of boards *a*, which are held together by means of battens *b*. The upper ends of these sides have rectangular openings into which the beam forms fit. By means of this construction the beam forms connect with the column forms so that when the concrete is poured a solid concrete framework is formed.

The sides of the column forms are nailed together at the corners but this is not sufficient to hold the form intact when the concrete is poured, consequently a system of strong braces is used for this purpose. The number of these braces and the frequency with which they are used is determined by the height and size of the column. Braces for columns having considerable height and a large area should be of heavy construction and located closely together, so that they may resist the pressure due to the wet concrete in the forms.

151. The form of brace shown in Fig. 67 is of the simplest type. It consists of four timbers *c* and *c'*, *d* and *d'*. Blocks *e*, *e'* are secured to the under side of the timbers *c* and *c′*, respectively, and blocks *f* and *f′* are secured to the top of the timbers *d* and *d′*. These timbers are assembled around the column form as shown and nailed to the form sufficiently to hold them in place until the wedges are set and driven into place. These

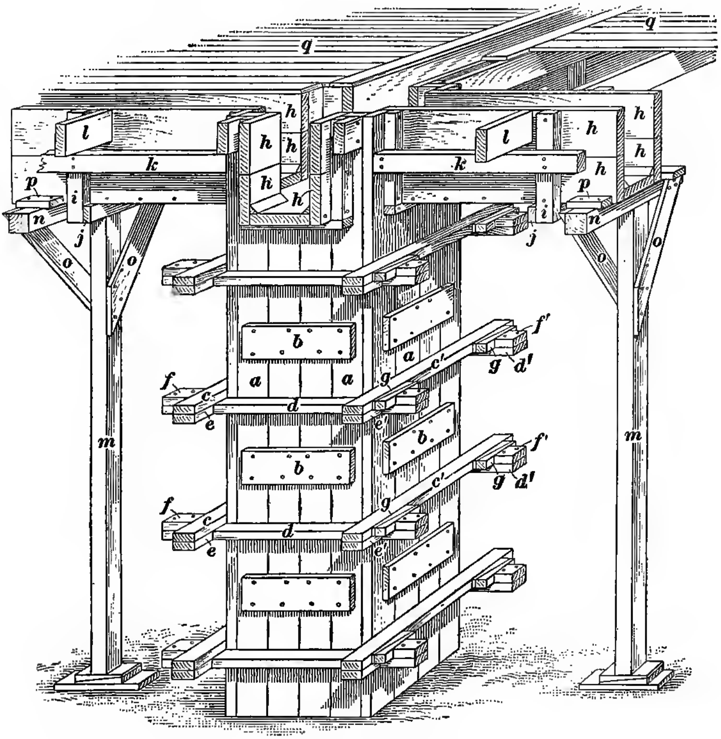
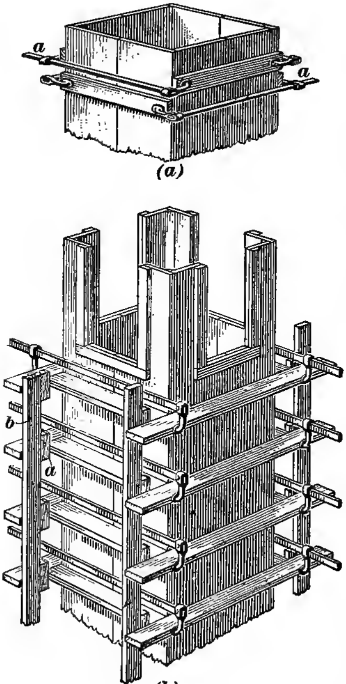


Fig. 67

wedges are used to draw the timbers into close contact with the column form.

There are many devices that are used for holding the column forms together. Some consist of metal bands, others of timbers with clamps attached, and some have bolts and wedges as shown in Fig. 19. They are all designed to be adjustable, so that after they are located in the position desired they can be tightened up and thus brace all parts of the column form.

152. In Fig. 68 is shown a device consisting of iron yokes *a*, which are attached to timbers. These devices are placed alternately on the sides of the column and thus brace all sides. In (*b*) the yokes are used to brace two sides of the column, and vertical timbers, as at *b*, are secured to the horizontal timbers shown and wedges *a* are driven into place until the braces are made rigid.



(*a*)

(*b*)

Fig. 68

153. Forms for Flat-Slab Floors.—To mold a flat-slab floor, a horizontal platform or floor at a proper height is required. Such a platform is usually made of planks, as shown in Fig. 69 at *a*, though metal plates are often used to advantage. The platform *a* is supported upon *stringers b*, which are planks set on edge and spaced usually from 4 to 6 feet apart, depending upon the weight to be carried and the size of the planks obtainable. The stringers are supported upon uprights *c* called *props* or *shores*. These are usually 4″×6″ timbers placed from 4 to 6 feet apart in rows. The stringers are nailed to the uprights and also are supported by blocks *d* nailed to the sides of the uprights. Since the uprights are cut to about the right length, the platform will be approximately at the right height; however, to obtain a fine adjustment and a truly level surface, the uprights are stood upon wedges as shown. These wedges consist of two wedge-shaped pieces of hardwood, and by driving them farther in the platform is raised, and vice versa. The wedges also make it easy to remove the forms, since, by knocking the wedges out, the forms are released from the concrete and can be taken apart.

A view taken underneath the forms and showing the stringers and shores in place is shown in Fig. 66 in conjunction with the column form previously described.

154. Forms for Beam-and-Slab Floors.—The forms for a beam-and-slab floor construction consist essentially of a platform of planks or boards, which is supported by stringers and posts as described in the preceding article. In addition, it is necessary to provide forms for the beams and girders. In Fig. 67 is shown one method of constructing wooden forms for this type of floor.

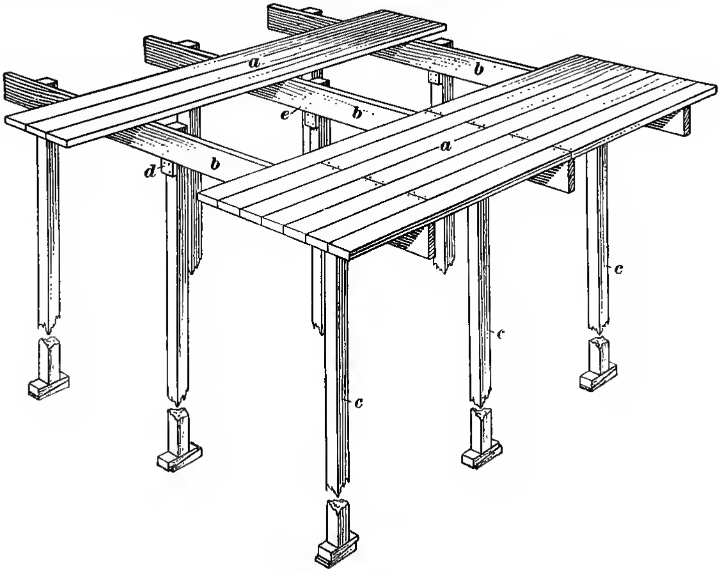


FIG. 69

The trough-shaped forms for the beams and girders are built up of planks or thick boards as shown at *h* and are fastened together by means of vertical and horizontal battens *i* and *j*, respectively. To the battens *i* are secured the horizontal timbers *k* on which rest the stringers *l* which support the forms for the slabs.

In this construction the entire weight of the floor is carried by the forms of the beams, which therefore must be made very strong. The ends of the beam forms are set into openings which have been previously made in the column forms, and are thus supported at the ends. When the beams are spaced at such distances between supports that they are likely to sag under the load of the wet concrete, intermediate supports in the form of posts must be used. The posts *m* are made of either 4″×4″ or 4″×6″ timbers with crosspieces *n* at the top and braces *o*, which are secured to the crosspieces and posts to make a rigid support. Blocks *p* are placed on each side of the beam forms and secured to the cross timbers to prevent the form from spreading when the concrete is poured. Wedges are usually placed under the posts as shown, to support the beams and to permit of adjustment.

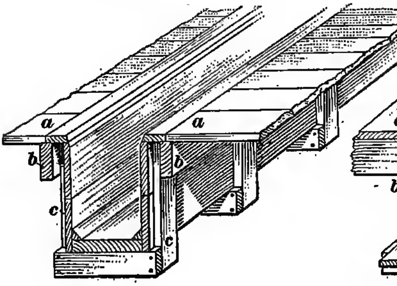


Fig. 70

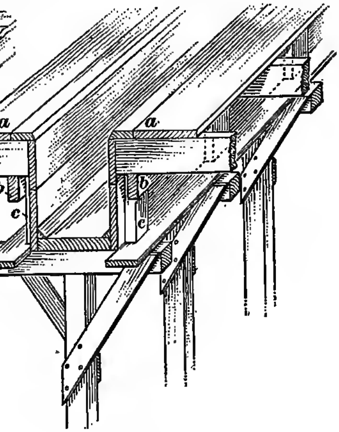


Fig. 71

155. Forms for concrete columns and beams require to remain in place for a longer period of time than forms for floors, because the columns and girders contain greater masses of concrete and consequently require more time for hardening. To permit the removal of the forms for the floor slabs for use in succeeding stories, the forms are so designed that those which support the floor construction may be removed without disturbing the forms of the beams and columns. The method of construction to permit this is shown in Figs. 70 and 71.

156. In Fig. 70 is shown a section through the form for a beam that runs at right angles to the direction of the planks that are used for forms for the slab. In Fig. 71 is a similar section through a form for a beam that runs parallel with the planks of the slab form. In both of these figures the top of the beam form has pieces of boarding that are beveled on their inner edges, and their outer edges terminate over the centers of the stringers *b*. By this means a joint is formed in the flooring around all beams so that when the floor forms are removed the separation between the floor forms and the beam forms will occur at these joints.

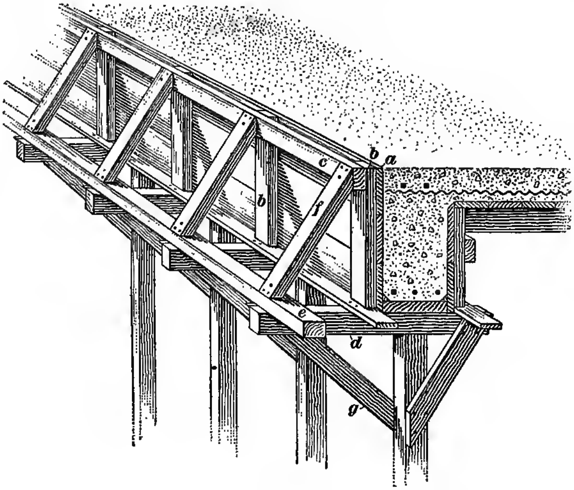


FIG. 72

157. In Fig. 72 is shown a design of form, brace, and support that is generally used for an outside wall beam or girder of concrete. This form is extended on the outside of the beam to the height of the top of the floor slab, as shown at *a*. The vertical batten *b* is also extended to the same height. A horizontal 2″×4″ continuous timber *c* is secured to these battens. The post support under the girder form is similar to those previously described. The cross-bar *d*, however, is extended and a horizontal 3″×4″ timber *e* is secured to these cross-bars, and between the timbers *c* and *e* braces *f* are placed every 2 or 3 feet apart to prevent the top of the form from moving when the form is filled with the concrete. The brace *g* supports the extended part of the cross-bar *d* and prevents it from sagging under the pressure on *e*.

An illustration of the use of wooden forms for columns and beams like those shown in Figs. 67 to 72 is given in Fig. 59. It will be seen that each of the column forms has six or seven battens enclosing it and each of the girders has four upright post supports, with the cross-braces at the top. These posts are stiffened by means of a horizontal timber which is placed midway in the height of the posts and securely nailed to them.

158. Treatment of Wooden Forms.—Wooden forms, both for plain and reinforced-concrete construction, are assembled as previously described. After they are set in place and lined up, they are given a coat of soap, crude oil, petroleum, or a similar substance, to prevent the concrete from sticking to the wood. Bolts which tie the forms together are also oiled. Wooden forms should not be put in place too long before filling with the concrete, because the wind and sun dry the wood and cause the boards to warp. When the forms are removed from the concrete they should be carefully cleaned, repaired if needed, oiled, and set up again. If they are not required immediately, they should be stored in a safe place for future use since they represent a very large investment.

159. Inspection of Forms.—While the concrete is being poured into the forms, it is customary to have a competent carpenter examine these forms and their supports, from time to time, in order to detect any weakness or deflection before it becomes too great to rectify. Any holes and defective joints in the forms should be plugged immediately when discovered.

160. Removal of Forms.—The order of procedure in the removal of the forms from a concrete construction consisting of floor slabs, beams, and columns is to remove the floor-slab forms first, then the beam and the column forms.

161. To remove the floor forms, such as shown in Fig. 67 at *q*, the floor stringers that run parallel with the beams, as shown at *b* in Figs. 70 and 71, must be pried loose from the battens *c*, whereupon the flooring usually drops away from the concrete and the entire floor form is thus removed. If the flooring still adheres to the concrete it is easily pried loose by means of a bar. The removal of the floor forms leaves the beam enclosure and its supports as shown in Fig. 73. This beam form is usually removed at the same time as the column form.

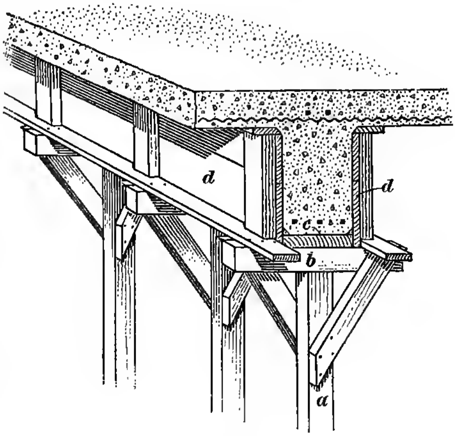


FIG. 73

162. It may be desirable to retain some of the support under the girders and beams for a time, as they are often required to carry a certain amount of load and may not have hardened sufficiently to carry the load without deflecting. The necessary support may be secured by retaining the posts *a*, Fig. 73, the cross-bar *b*, and the bottom part *c* of the form of the girder. The side pieces *d* may be removed, so that the air may reach the concrete and facilitate its hardening.

163. When the Forms May Be Removed.—There is no definite rule for the length of time which must elapse after concreting before the forms can be removed. The time depends upon the weather, the kind of cement and aggregate, the span of construction, and the thickness of the slab or mass of concrete. Only a competent and experienced person can judge when the proper time has arrived. Under favorable conditions the time may vary from one week, for slabs, to three weeks or a month for beams, girders, and columns. Some cities have building codes containing a schedule indicating the minimum lengths of time that forms must remain in place after the concrete has been poured. This is based on the concrete having been placed when the temperature was above 32° F. If concrete is placed when the temperature is below 32° F., a special permit must be secured in some cities before the forms may be removed.

CONCRETE-BLOCK CONSTRUCTION

SHAPES OF BLOCKS

164. Definition.—A **concrete block** is a building unit formed of concrete molded into a convenient form. The common shape of a concrete block is such that its exposed surface is a rectangle. The block may extend through the wall, or it may not. In every case, provision is made for an air space in the wall, and the means by which this is accomplished vary widely and are covered by many patents. The purpose of this air space is to prevent heat, cold, and dampness from penetrating the wall.

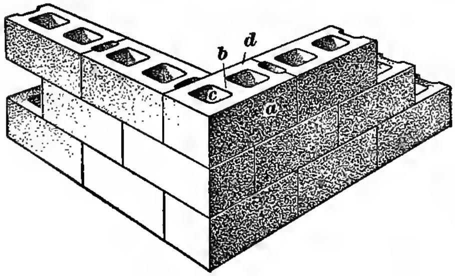


FIG. 74

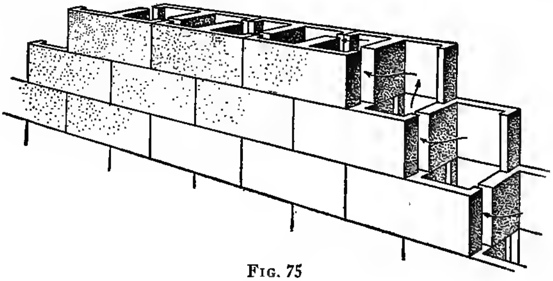


FIG. 75

165. One-Piece Blocks.—Blocks that extend through a wall are termed *one-piece* blocks. The outer part is called the *face section;* the inner part, the *back section;* and the partitions that unite the face section to the back, the *webs,* or *withes.* All such blocks are termed *hollow blocks.*

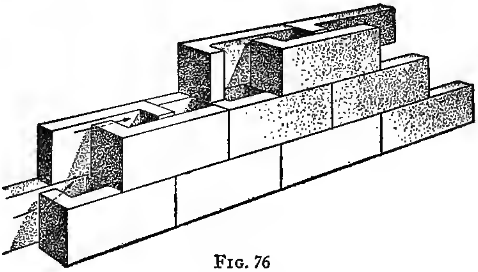


FIG. 76

Fig. 74 shows the general form of a one-piece hollow block. The face section of this block is shown at *a*; the web, at *b*; the hollow spaces, at *c*; and the back section at *d.* The spaces in one block connect with those in the block above and the one below, forming a continuous air space from the top to the bottom of the wall. Different types of one-piece blocks differ, however, in this arrangement.

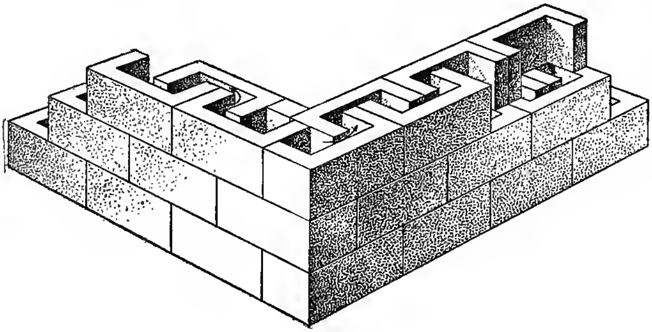


FIG. 77

In hollow blocks, the number of webs on each block may vary from two to four or more; three is the common number, as it affords two or, as in Fig. 74, three, hollow spaces.

166. Two-Piece Blocks.—Blocks in which the face section and back section constitute two separate parts are known as **two-piece blocks.** These blocks are of various forms and are often patented. The more common forms are designated as **T** shaped, shown in Fig. 75; **L** shaped, in Fig. 76, and **U** shaped, in Fig. 77, because their general outlines conform to the shape of these letters. These blocks are placed so as to provide as large air spaces as possible between the outer and inner surfaces of the wall.

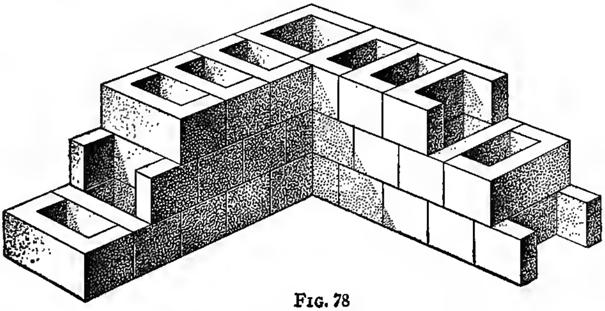


Fig. 78

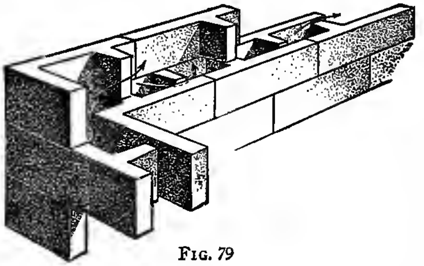


Fig. 79

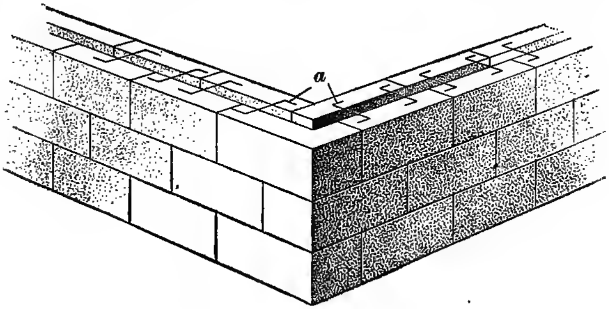


Fig. 80

Fig. 78 shows a wall that is made up of **U**-shaped blocks laid crosswise, instead of lengthwise, as in Fig. 77.

The type of block used in the wall shown in Fig. 79 is an unsymmetrical form of the **T**-shaped block.

In laying two-piece walls, the blocks on the back of the wall break joints with those on the front, so that the only joints extending through the wall are the horizontal ones between the courses.

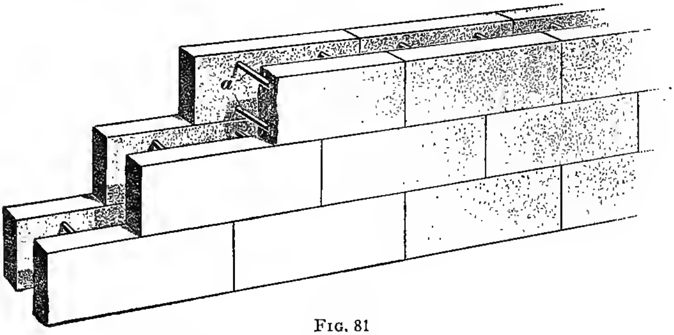


Fig. 81

In Fig. 80 is shown a form of block in which two slabs, one forming the face and the other the back, are joined by metal ties *a* laid in mortar on top of each course. This gives the general effect of a one-piece block, the only difference being a continuous air space throughout the wall, as the transverse webs are omitted and the metal ties perform their function.

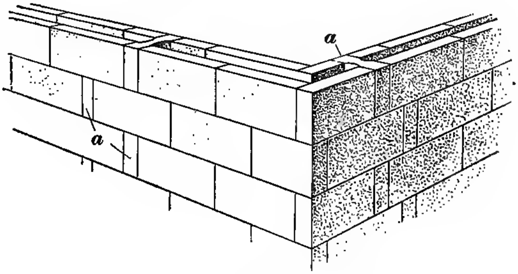


Fig. 82

Another type of two-piece block that produces a continuous air space is shown in Fig. 81. Each pair of blocks is permanently united by means of four rods *a*, that are embedded during the casting process.

Fig. 82 illustrates a type of two-piece wall in which the face and the back portions of the blocks are laid entirely separate, the two halves of the wall being connected by headers *a*.

The wall shown in Fig. 83 is built up of blocks that have triangular projections. As indicated by the arrows, there is a very free passage of air through the blocks, in both horizontal and vertical directions.

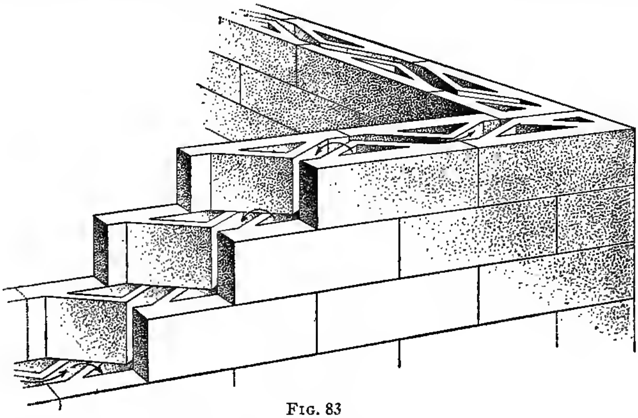


Fig. 83

MANUFACTURE OF BLOCKS

167. Processes.—There are three different processes that may be used in the manufacture of concrete blocks; namely, pouring, pressing, and tamping the concrete into forms or molds. The pouring process makes use of a comparatively wet mixture and produces an excellent product. A medium-wet or sometimes quite dry mixture is used in the pressing process, the concrete being pressed into the forms by means of hydraulic or other power. The tamping process employs a dry mixture, the material being shoveled into the forms and tamped into place.

Blocks may be cast in a very simple form of mold, but are generally formed by means of machines. Numerous types of molding machines, using all three of the processes mentioned, have been placed on the market.

168. Cement-Block Machines. — Cement-block machines are made in many designs, each manufacturer claiming that his machine possesses certain superior features. In all these machines there is a framework that supports the mold, in which the block is cast, at a convenient height so that it can be filled and handled easily. The sides and ends of the mold are usually hinged together or connected in such a manner that the mold can be easily opened and closed.

Most of the machines on the market are what are known as the *face-down* type, in which a comparatively dry mixture of concrete is used. In these machines the face of the block is at the bottom of the mold during the period of filling. The wood or metal cores, which are placed in the mold to form the hollow spaces *c*, Fig. 84, occupy a horizontal position while the mold is being filled. In the machine shown in the figure, after the block is molded the mold is turned by means of the lever *a*, and the core can be removed vertically. The semicircular cores are attached to the mold and are removed with the mold. In this block there are special faces on the top and bottom of the block, as it is designed to show on opposite sides of the wall.

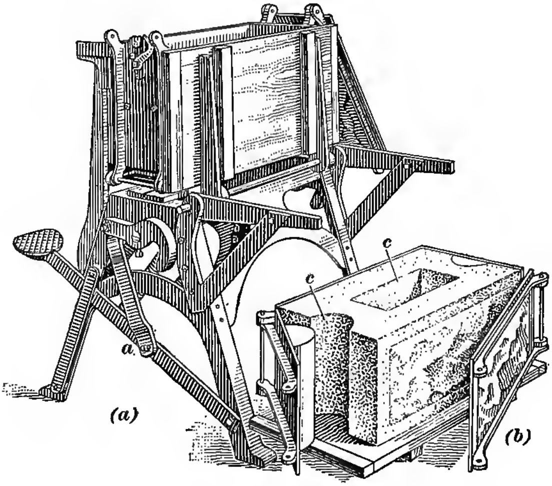


Fig. 84

169. Other types of machines are those known as *side-face* machines, because the face plate is on one side of the mold; and *press-block* machines, which press the concrete into the form of blocks. Many of these machines have interchangeable face plates whereby the exposed face of the block can be finished in different designs such as plain face, rock face, imitation ashlar, tooled face, and other finishes that are used in cut stone work.

SURFACE FINISHES FOR BLOCKS

170. Concrete blocks may have surface finishes similar to those described for walls of poured or cast concrete. Some additional finishes of an attractive character are also possible because of the manner in which the block is made.

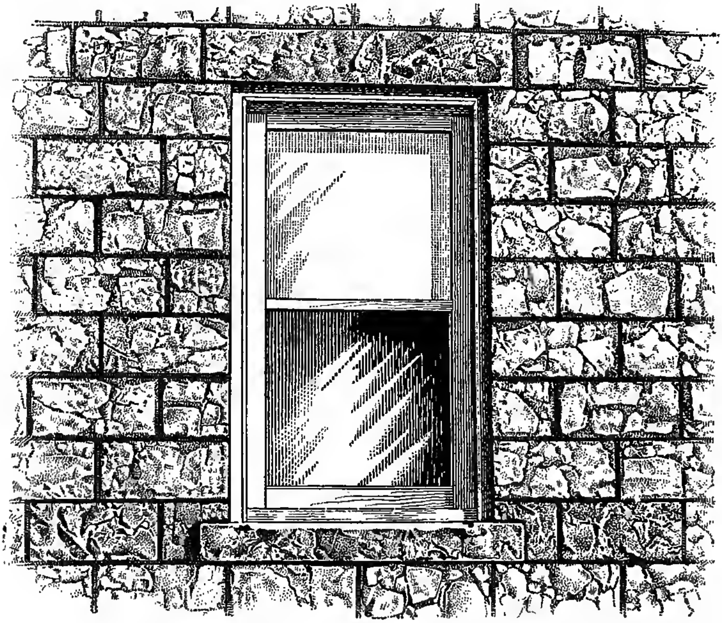


FIG. 85

For blocks that are to be veneered with a special mixture of aggregate, the mixture is placed in the form first and the rough concrete is deposited on top of it. The treatment of the block after it is taken from the form may be by any of the processes described for walls.

171. There is a form of veneer for the blocks which presents a face consisting largely of actual stone that is very pleasing. To secure this form of surface, a layer of sand about ½ inch in thickness is first spread over the bottom of the form. Upon this sand are placed thin pieces, or chips, of granite having irregular shapes and sizes, these pieces being usually split by hand from larger pieces. They should be laid in the form as close together as possible without overlapping. A rich mortar consisting of one part cement and one part sand, mixed very wet, is then poured into the forms, sufficient mortar being used to cover the stones. Immediately after pouring this mortar, the forms are filled with ordinary concrete, and the blocks are left in the forms until the following day. They are then removed, stored, and allowed to dry slowly, as is customary with ordinary concrete blocks, and without further treatment are ready to be placed in the wall. A wall formed of this style of concrete blocks is shown in Fig. 85. The joints between the blocks may be pointed with a colored mortar and finished in the form of a raised bead.

SIZE AND WEIGHT OF BLOCKS

172. Size.—The size of a concrete block from the face section to the back is variable, because the width is regulated by the required thickness of wall. This dimension can be changed by lengthening or shortening the connecting webs. It is customary, however, in thicker walls to make some variation in the thickness of the face section and the back of the blocks. In this way a larger bearing surface is afforded and increased resistance to unequal expansion is obtained in case of excessive heating of one side of the wall. On the other hand, the decrease in thickness of face and the back sections in narrow walls carrying light weights not only serves to increase the insulation afforded by the interior air space, but also effects some saving of material. The thickness of walls as customarily specified are as given in Table III.

173. The length and height of the blocks are determined by three factors: (1) Facility in handling and laying; (2) preservation of a multiple system; and (3) appearance in the completed wall.

The general tendency has been to make as large blocks as possible in order to reduce the manufacturing cost per square foot of wall. The expense of handling large blocks is, however, objectionable. Consequently, blocks 16 inches in length are the most common size, being light enough in weight to be handled by one man.

TABLE III

THICKNESS OF WALLS FOR BUILDINGS OF VARIOUS HEIGHTS

(*Thickness of Partitions, 4 to 6 Inches*)

Height of Building	Thickness of Wall, Inches				
	Basement	First Story	Second Story	Third Story	Fourth Story
One story	12–15	8–10			
Two stories	15–17	10–12	8–10		
Three stories	17–20	12–15	10–12	8–10	
Four stories	20–22	15–17	12–15	10–12	8–10

The heights of the courses are generally 4 inches, 8 inches, or 12 inches, which simplifies construction.

174. Weight.—The weight of a concrete block is determined by its composition, its size, and its percentage of air space.

Weight is important because of the cost of handling and because of the load on the lower courses and the foundation. In general, the aim should be to keep the weight low enough in one-piece blocks so that one man can handle a block on the wall. When these weights are exceeded, it usually means paying an extra man to assist in handling the blocks, and he is necessarily idle part of his time.

AREAS, VAULTS, AND RETAINING WALLS

AREAS

INTRODUCTION

1. Definition.—An area is an enclosed sunken space that is formed outside of the foundation wall of a building for the purpose of admitting light and air into a basement or cellar, or to provide access to a basement or cellar entrance.

2. Types of Areas.—Areas may be classified, according to their purpose, into three types. One type is designed to allow of *lighting* a basement or cellar of a building; examples of this type are shown in Figs. 4 and 6. Another type is designed to be used as a *means of access* to a basement or cellar, as shown in Figs. 7 and 16. The third type is designed to be used as a *means of access* to a basement and also to allow of *lighting* the basement; this type is shown in Figs. 10 and 14.

3. Parts.—Areas consist of walls and of the following parts; namely, steps, floors, drains, balustrades, railings, gratings, and covers.

The **walls** which enclose the sunken space and keep the soil surrounding the area in place, are called *area walls.* These walls should be strong enough to resist the pressure against the wall, known as *lateral pressure,* due to the weight of the soil adjacent to the area. The principles that govern the design of these walls are the same as those used in the designing of

COPYRIGHTED BY INTERNATIONAL TEXTBOOK COMPANY. ALL RIGHTS RESERVED

retaining walls, a subject which is discussed later on in this Section.

Area steps are installed to provide a means of access between the grade level of the soil or the sidewalk adjoining the area and the area floor.

A **floor** is installed in the area to protect the foundations of the area walls, by keeping the foundation walls of the building dry, and also to form a pavement in the area.

Drains are installed in areas that are paved, to carry away the water from the area floor.

Balustrades, railings, gratings, and **covers** are installed to prevent persons from falling into the area and being injured.

In the area illustrated in Fig. 14, the enclosing walls are shown at *a, a,* the steps between grade level and the area floor are shown at *b,* the area floor at *c,* and the floor drain at *d.* In this illustration, a railing, shown at *e,* is used to prevent persons from falling into the area, while in Fig. 19 (*a*) is shown a grating *e* that is intended for this purpose.

4. Building Laws.—The building laws, or codes, of nearly all cities, require areas that are located in front of buildings and which extend into sidewalk space, to be covered or enclosed in such a manner as will insure the safety of pedestrians. These codes often also place restrictions on the size and the location of the area, and should be consulted when areas are designed to be constructed in such cities.

AREA WALLS

5. Materials.—Area walls may be built of terra-cotta tile, brick, stone, concrete in the form of blocks, plain concrete which has been poured, or reinforced concrete; that is, concrete into which steel rods or steel mesh have been embedded.

The choice of material depends upon what is available in the locality where the work is to be done, its cost relative to other materials, and sometimes upon what kind of material is used in the foundation walls of the building.

6. Excavations.—Excavations for areas should be made sufficiently large and deep to receive the walls and footings and also to allow ample space outside of the walls for the performing of other operations that may be necessary, such as bracing of the soil, pointing of the wall, waterproofing, or building of forms for concrete if concrete construction is contemplated. Special care should be taken, in making the excavations, not to disturb the adjoining soil or cause it to fall into the excavated space while the area walls are being built.

As a general rule, all excavations for walls that are to be erected in localities that are subject to freezing weather should be carried down to a level that is below the frost line.

7. Bracing of the Soil.—If the soil which surrounds the area is likely to break or fall into the excavated space before the area wall is built, or if the excavation is being formed in sand or gravel, it will be necessary to erect braces or supports to hold this soil or gravel in place temporarily. If the wall of the building has been previously erected, the bracing may be of the form shown in Fig. 1. To construct this bracing the posts *a* are first driven into the soil and the upper ends are braced against the building by means of the timbers *b*, these timbers being nailed to the blocks *c*, secured to the wall of the building. The posts should be located a sufficient distance outside of the area wall to permit of its construction, and the timbers *b* should also be placed high enough so that they will clear the top of the wall when it is built. The boarding *d* should be of matched

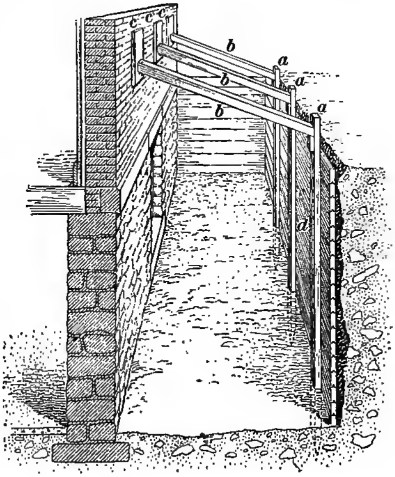


FIG. 1

material with the tongue driven into the groove to stiffen the boarding between the posts.

8. If the wall of the building has not been erected, the bracing of the soil may be accomplished as shown in Fig. 2. In this form of construction the posts *a* are braced by means of the timbers *b* and *c*, and these timbers are securely nailed to the stakes *d*, and the posts *a*. If this construction is used it will also be necessary to locate the posts a sufficient distance outside of the wall to permit of the building of the wall and it will be necessary to build the wall around the timbers *b* and *c*. After the mortar in the wall is thoroughly set, these braces are removed and the openings filled with masonry.

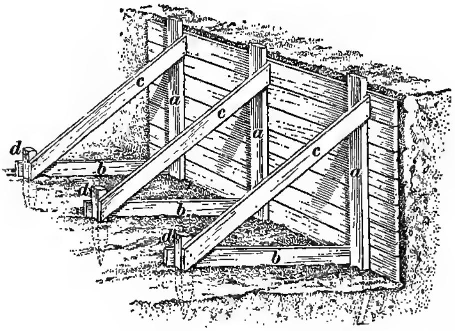


FIG. 2

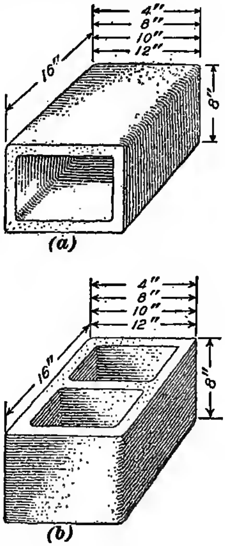


FIG. 3

9. Walls of Terra-Cotta Tile.—There are two kinds of tile that are used for building area walls, the *hollow building tile* and the *conduit tile*. Both of these kinds are vitrified and salt-glazed and therefore are impervious to water.

Two forms of hollow building tile are shown in Fig. 3. In (*a*) is shown the form and the sizes in which the wall blocks are made, and in (*b*) is shown the form of tiles used for the corners of the wall, together with their sizes.

In Fig. 4 is shown an area having walls constructed of *hollow building tile*. The foundation walls of the building are also constructed of the same material and the blocks shown at *a* are left projecting from the wall to form a tie with the area walls, which are built after the foundation wall is completed. In the top row of tile, the standard corner tile is not used. Instead, a regular wall block is used. The open end of the tile in the top course has been filled with broken pieces of tile bedded in cement mortar and coated to make a neat finish, as shown at *b*.

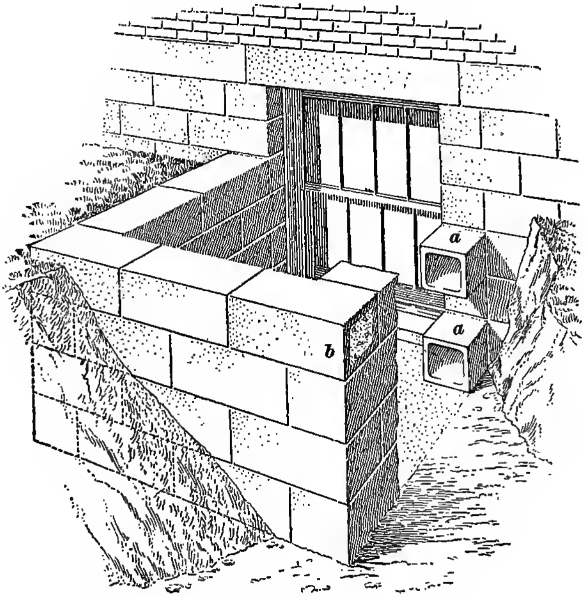


FIG. 4

Forms and sizes of *conduit tile* are illustrated in Fig. 5. This type of tile is made for the purpose of carrying underground telephone, telegraph, or other electrical wires. For building purposes, however, tile having slight defects which make them undesirable for conduit purposes, and classed as *seconds*, are often used and are perfectly satisfactory for walls. In (*a*) is shown a tile containing four openings, called cells. This tile is 9 in.×9 in. in cross-section. In (*b*) is shown a tile 9 in.×13 in. in size containing six cells. The lengths of these tiles vary from 18 inches to 36 inches.

10. Walls of Brick.—Brick walls of areas should be constructed in the same manner as brick foundation walls. The brick should be hard, dense, and thoroughly bonded together. All the joints and crevices should be filled with cement mortar so as to make a strong wall, and the joints on the faces of the wall should be carefully pointed to keep out water.

Brick area walls are sometimes built in the semicircular form shown in Fig. 6. This form of area is used for small windows that do not extend very far below the grade level, and the walls are usually made of a thickness that is equal to the length of one brick. If, however, the diameter of the semicircle exceeds 3 feet, the thickness of the wall should be increased.

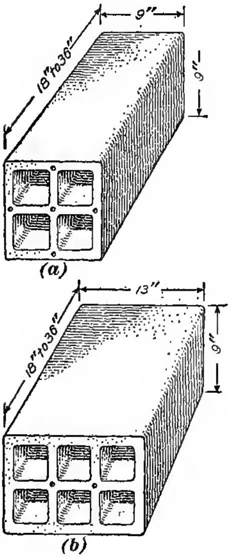


Fig. 5

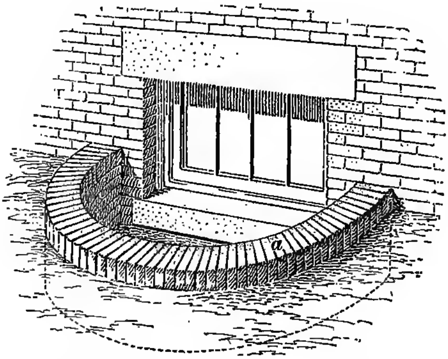


Fig. 6

11. The **coping** is a feature designed to prevent water entering the top of the wall. In Fig. 6, it is formed of regular shaped brick as shown at *a*. The bricks are laid on their long narrow edges and the joints are entirely filled with a mortar made of equal parts of Portland cement and sand to render it impervious to water. The cement-mortar joints on the top of this coping should be troweled flush with the brick so that water will not stand on the surface.

An example of an area which is used as a means of access to a basement, and which has brick walls, is shown in Fig. 7.

The walls *a* extend above the grade level and take the place of a railing. The tops of these walls are also protected by means of brick copings *b*, special shaped brick *c* being used to form the corners of the coping. At *d* is shown one of the stone steps leading down into the area.

The walls of the area shown in Fig. 8 are rather high and must be made strong to resist the lateral pressure produced by the adjoining soil. They are assisted in doing this by the brick arches *a*, which are built at suitable intervals. The coping for the walls is formed of thin flat stones *b*, and a coping of similar character is used for the walls which form the braces, as shown at *c*. These coping stones should be long, to insure few joints through which water can enter the wall, and they should be cut so that these joints will occur between the posts of the rail-

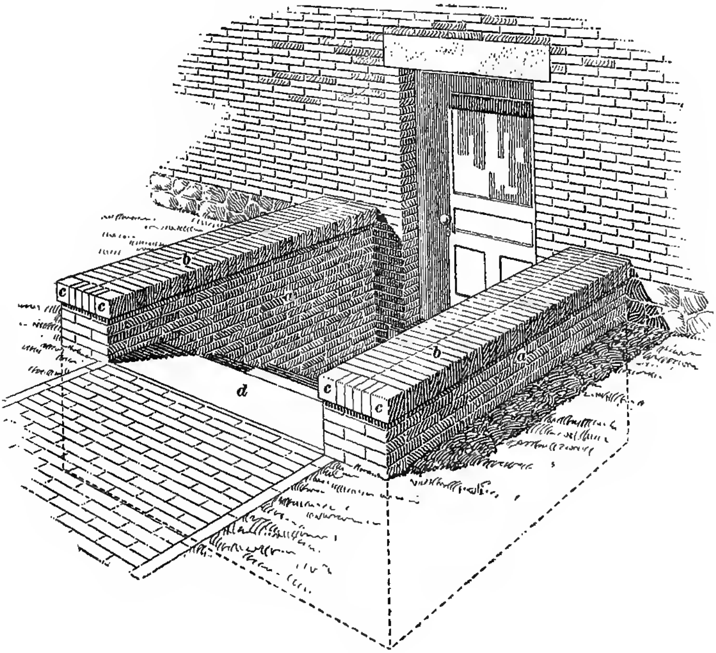


FIG. 7

ing, as at *d*, for the stones are liable to be broken by the cutting of holes for these posts if the holes are near the ends of the slabs.

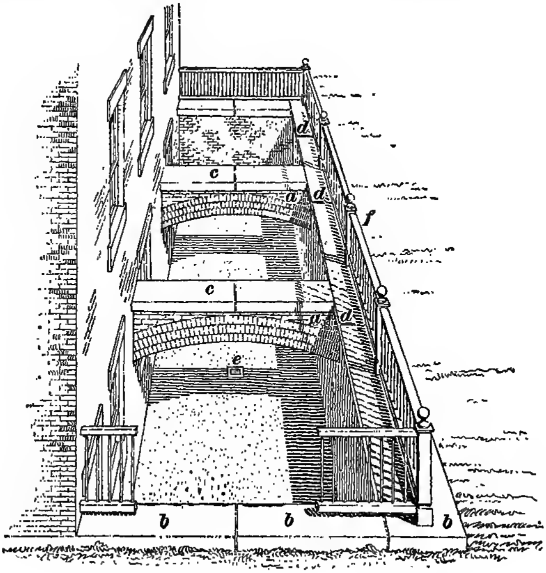


FIG. 8

All copings should be sufficiently wide to project from 1 inch to 2 inches beyond the faces of the wall, and the under side of this projection should be cut in such a manner as will cause the water from the coping to drip free from the wall. Coping stones cut in this manner are said to be cut with a *drip*. In Fig. 9 a coping stone is shown at *a* and the drip is shown at *b*. No drip is cut on the outer edge of this coping, as the soil is filled against the wall and the drip is not required.

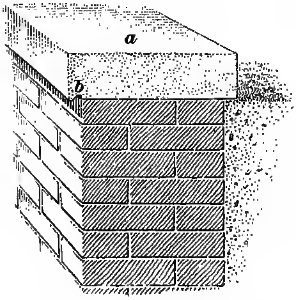


FIG. 9

12. The area shown in Fig. 10 has brick walls *a*, reinforced by means of brick buttresses or pilasters *b*, to assist the wall in resisting the pressure from the adjoining soil. These walls extend above the grade to act as a railing, and have stone copings as shown at *c*. The coping is of the design shown in Fig. 11 at *a*. The top is formed with a slope to each side to drain away the water, and both edges are cut with a drip, as shown at *b*.

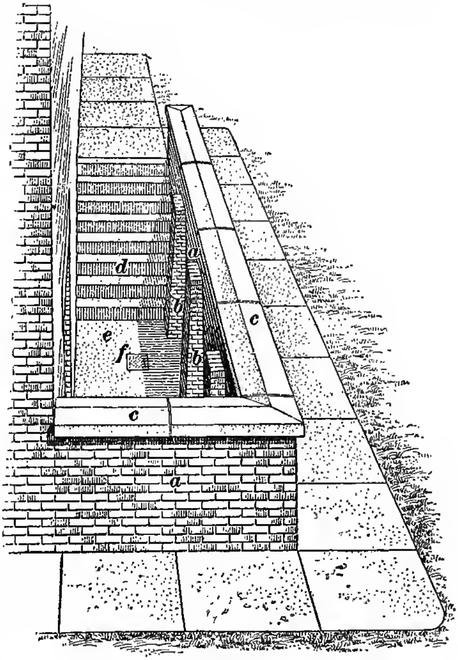


Fig. 10

13. A coping of this same general shape may be made by pouring concrete into wood forms. The coping may be in sections, or slabs, similar to stone slabs, or it may be formed on the wall in one section. To cast it in sections, wood forms of the shape shown in Fig. 12 (*a*) are used, and after the concrete has become hard the slab is removed from the form and placed on the wall as shown at *a* in view (*b*). If the coping is cast directly on the wall, a form is erected as shown in Fig. 13 and into it the concrete is poured. This form requires wooden posts *a* to which the boards *b* are secured. The posts outside of the wall may be driven into the soil to secure them in place, but the posts on the inside of the area wall will require braces. At *c* is shown a brace which is secured both to the post and the form, and the

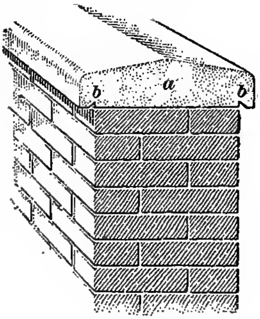
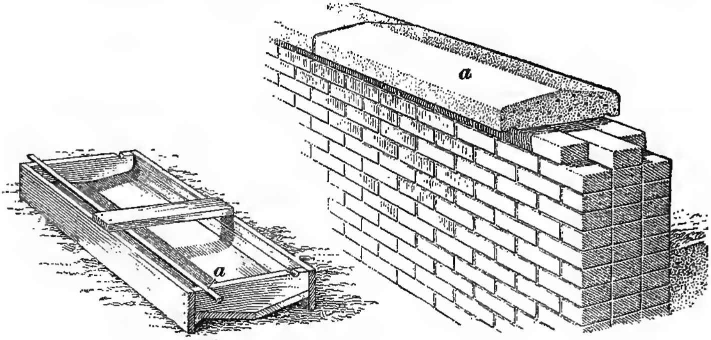


Fig. 11

opposite end of this brace is placed against the foundation wall of the building.



(a) (b)

Fig. 12

At *d* is shown concrete which has been placed in the form, and at *c* is a template which has the lower edge formed to the shape desired for the top of the coping. This template also has running edges and shoulders as shown at *f*, and by operating it back and forth the surface of the concrete is formed into the shape desired. After the concrete has hardened sufficiently to permit of the removal of the forms, the edges *g* of the coping should be slightly rounded by rubbing with a piece of sandstone and some water.

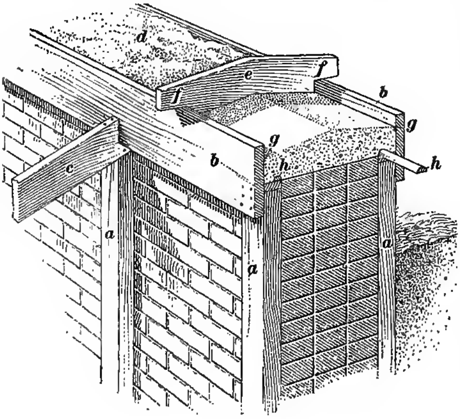


Fig. 13

All concrete copings should have drips similar to those shown for stone copings. These drips may be made in the concrete by placing half-round wooden moldings in the forms, as shown in Fig. 12 (*a*) at *a*, and in Fig. 13 at *h*.

Wooden forms for concrete copings should also be designed to provide suitable openings for iron posts of railings or balustrades, where such members are contemplated.

As soon as the wooden forms are removed the concrete copings should be examined and carefully repaired with cement-and-sand mortar. Concrete coping slabs should be set in cement mortar and the joints between the slabs should be filled and pointed in the same manner as the joints between stone slabs.

Copings, or coverings, are occasionally made of rich cement mortar not less than 1 inch thick and troweled on so as to form a smooth sloping surface. This treatment is a cheap one, but the work will not last a great length of time.

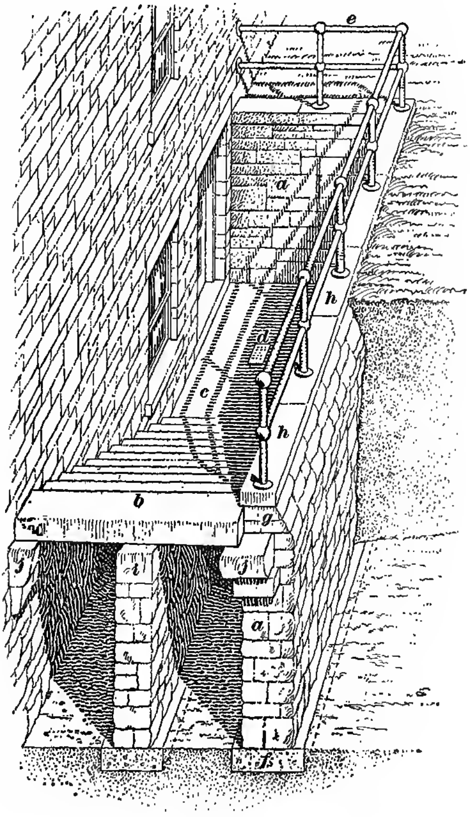


FIG. 14

14. Walls of Stone. — Stone for area walls should be of a dense and nonporous variety and laid only in cement mortar. Walls of this character are usually made in rubble work; an example of such a wall is shown in Fig. 14 at *a*. This wall has a projecting footing, as shown at *f*, which is formed of concrete, but this may be of large stone if so desired. These footings are usually made from 6 inches to

8 inches thick and project about 6 inches beyond each face of the wall. The top of this wall is tapered as shown at *g,* to permit of the use of a narrow coping *h,* as a coping made wide enough to cover the entire thickness of the wall would be unnecessarily expensive. The joints in the masonry of this sloping, or tapered, surface should be carefully pointed to prevent water entering the wall.

Areas of this type that are 6 feet or more in width should have an additional wall as shown at *i,* known as a dwarf wall, to support the middle of the stone steps. The ends of these steps may rest on stones that project from the foundation and area walls as shown at *j,* or they may extend into the walls for a bearing. If of this latter construction, the steps must be set while the walls are being erected.

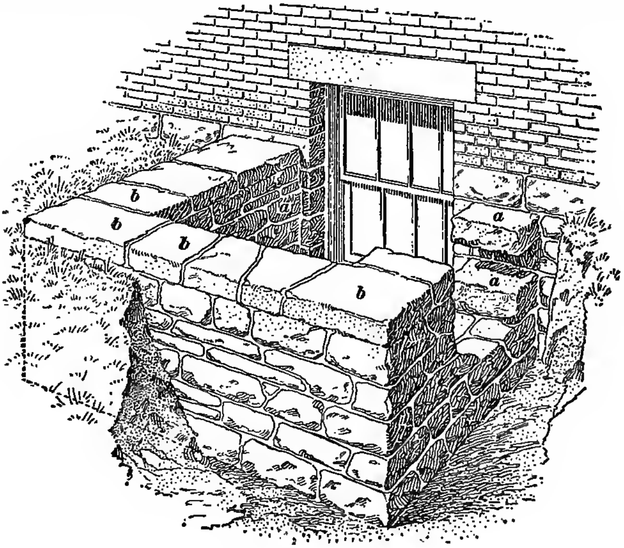


FIG. 15

The area shown in Fig. 15 also has walls of rubble stonework, and although the area is small the walls are usually made 18 inches thick, as it is not economical to build them of less thickness in this material. At *a* are stones that project from the foundation wall of the building to furnish a tie, or bond, for the walls of the area. The coping of these area walls is formed of roughly dressed stone, as shown at *b*.

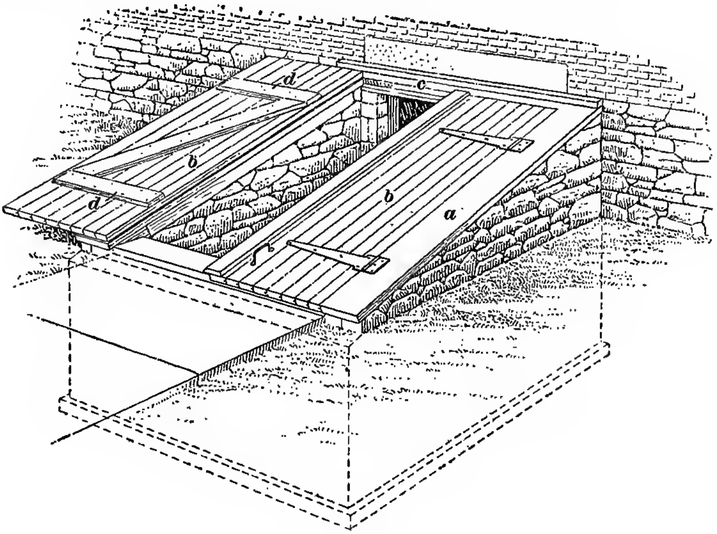


FIG. 16

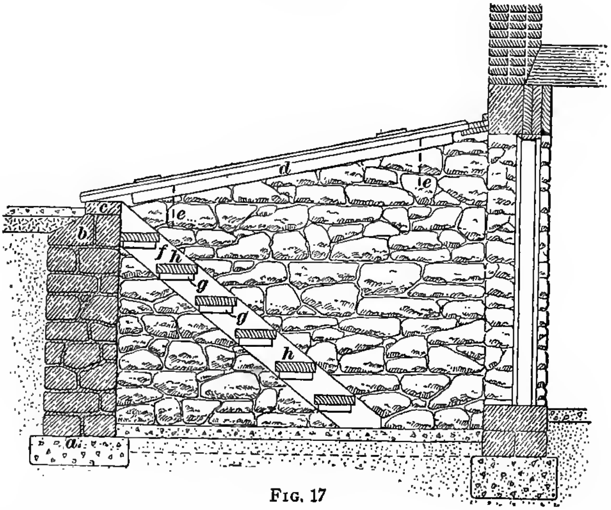
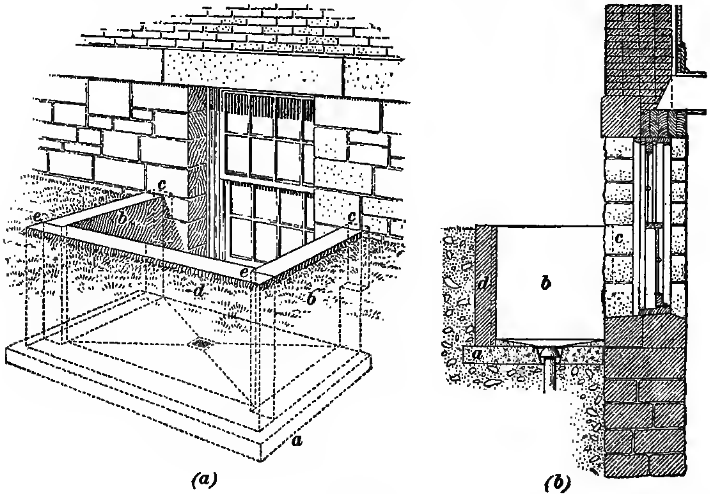


FIG. 17

15. The area shown in Figs. 16 and 17 is one that is frequently used as an entrance to the cellar of a private house.

The walls are usually built of brick or rubble stone and sometimes have a footing, as shown in Fig. 17 at *a*. The top of the wall is usually tapered as at *b*, and a single slab of stone *c* is used to form a coping and also to serve as the top step of the stairs. The side walls of this area are carried up the full thickness, and a wooden plate *d* is placed on the top of the wall and secured in place by means of anchor bolts *e* set in the walls while they are being erected.

16. Stone slabs for area walls, as shown in Figs. 18 and 19, are used extensively in localities where sawed flagstones are easily obtained. These slabs are made 4 inches, 5 inches, or 6 inches thick, the thicker slabs being used for the larger-size areas. The edges of these slabs should be cut true and even to insure close-fitting joints and finished surfaces where they are exposed.

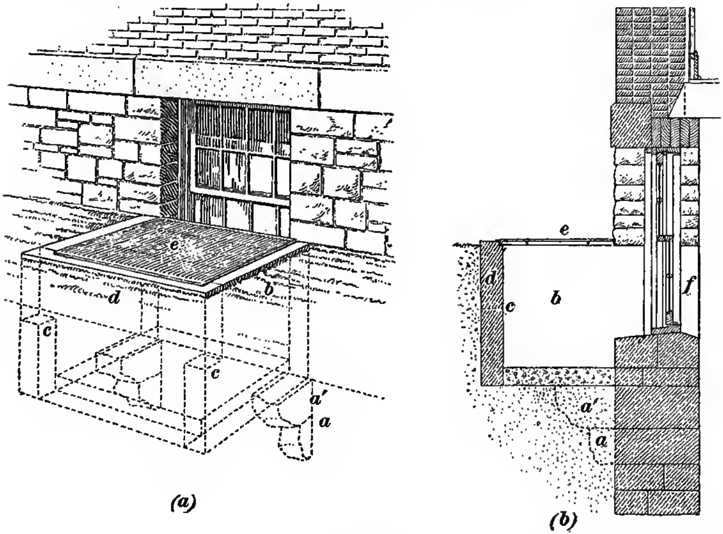


(a) (b)

Fig. 18

The type of construction shown in Fig. 18 is most commonly used. In this construction a part of one end of the slab *b* is set into a recess *c* made in the wall of the building, and the front slab *d* has each end recessed at *e* to receive the ends of the slabs *b*. After these slabs are assembled they will require to be braced until the soil is filled around the wall; when this is done, the slabs will be retained in their proper position by the pressure from the soil.

Footings are usually required for these slabs, and when the area is to have a concrete floor this floor is often placed before the slabs are set and made sufficiently large to form a footing, as shown at *a*. Areas of the type shown in Fig. 19 are sometimes used where the soil is not sufficiently solid to carry the area walls. In this form of construction the area walls are carried entirely by the walls of the building and require to be erected at the same time as the building walls.



(*a*) (*b*)

Fig. 19

The method of constructing this area is to project the stones from the foundation wall as shown at *a*, *a′*, and place the side slabs, one of which is shown at *b*, on these stones. These side slabs extend through the foundation wall, as at *f*, view (*b*), and form the jambs of this part of the window opening. The front ends of these slabs are cut with a shoulder as shown at *c* in view (*a*), the front slab *d* being formed with lugs on each end that will rest on these shoulders.

View (*b*) is a section through the area and basement window. In this construction the projecting stones *a*, *a′* are made sufficiently wide to form a bearing for the floor of the area when it is placed.

17. Walls of Concrete Blocks.—Concrete blocks such as are shown in Fig. 20 are laid and bonded in the same manner as the terra-cotta hollow building tile which are shown in Fig. 5. The standard form of block is shown in Fig. 20 (*a*); a block that is used for the corners of the wall is shown in (*b*), and a form of block that is finished on the top, sides, and ends and designed to be used as a coping member for the corners of the walls, is shown in (*c*).

Walls formed of concrete blocks, when liable to be subjected to moisture, should be waterproofed. This may be done by adding a waterproofing compound to the concrete when it is mixed, or the blocks may be treated with a coating after they are formed. Walls may be waterproofed after they are erected, if so desired, as described later under the head of Waterproofing.

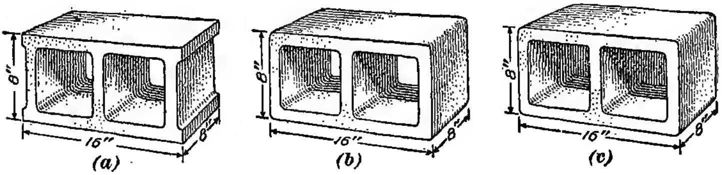


Fig. 20

18. Walls of Plain Concrete.—Walls of plain concrete require the erection of wooden forms into which the concrete is poured. When these walls are such that a footing is required, the footing, as shown in Fig. 21, at *a*, is usually installed first and the concrete allowed to harden, after which the forms are erected for the wall. In this method of construction provision should be made to bond the footing and the wall together to prevent the wall from slipping off the footing on account of the lateral pressure from the surrounding soil. This is often accomplished by placing pieces of stone in the concrete footing so that they will project above the surface, as shown at *b*. In this illustration are shown wooden forms and braces such as are frequently used in constructing poured concrete walls.

The posts *c* are set on the concrete footing *a*, and these posts are held in place and braced by means of the timbers *d* and *g*. The bracing members are nailed to the stakes *e*, and boards *f* are fastened to the posts as shown.

When the excavations are made in a soil that is sufficiently firm to retain its form and not fall into the excavated space, the excavations may be made the exact size of the outside lines of the wall and only the inside forms need be used, the concrete being poured between the soil and these forms. As the concrete is being poured, the part next to the forms should be thoroughly worked or puddled with a tool to insure the wooden forms being entirely covered with the fine parts of the concrete. This working of the concrete will tend to produce a smooth wall surface and one that is free from voids or exposed gravel, and will also tend to make a surface that is impervious to water.

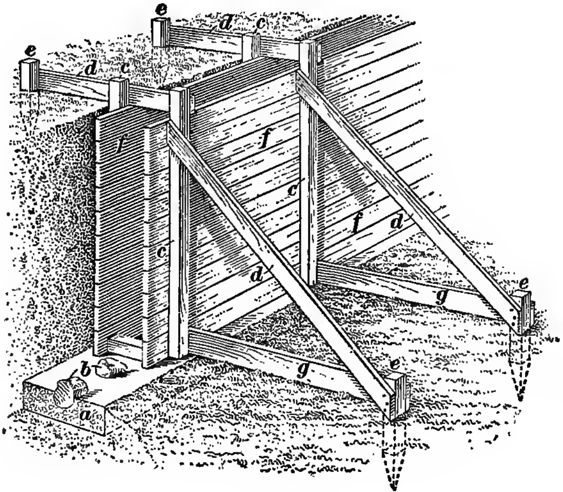
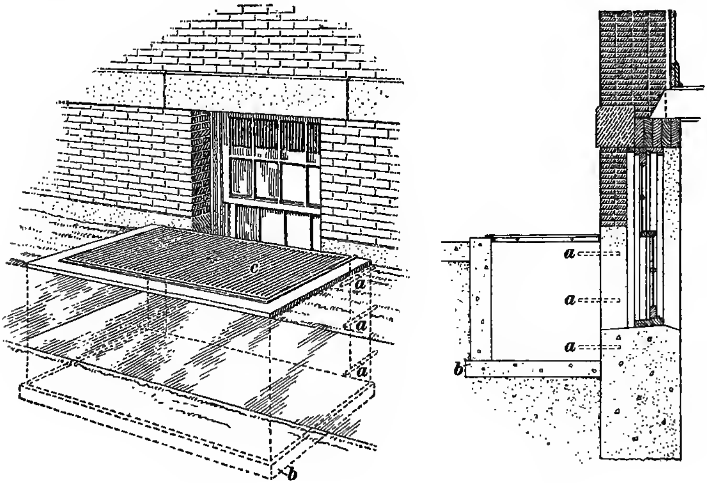


FIG. 21

When the foundation walls of the building are to be of concrete, the concrete area walls should be cast at the same time as the foundation walls to insure a bond between them. Small areas having concrete walls 6 inches thick, as shown in Fig. 22, are, however, often anchored, or tied, to the foundation walls by means of bars of steel, as shown at *a*. These bars are placed in the concrete wall of the building while it is being cast and extend into both the area and foundation walls about 10 inches. In the area shown in this illustration, the floor concrete has been completed before the forms for the walls were erected, and the floor serves as a footing for the wall, as shown at *b*.

Large areas may be enclosed with walls formed of plain poured concrete if so desired. Such walls are usually made of the same thickness as walls of brickwork.

19. Walls of Reinforced Concrete.—Reinforced concrete is often used for area walls that are very high and which consequently are required to be very strong in order to resist the great pressure due to a large amount of soil that adjoins the area. Reinforced walls, however, are not required to be so thick as plain concrete walls, consequently there is a considerable saving of concrete.



(a) (b)

Fig. 22

The methods used in erecting the wooden forms for these walls and the casting of the wall are similar to those for plain concrete work. The steel bars that reinforce the concrete are placed in the wooden forms, and securely fastened in the positions required before the concrete is poured. Walls of this character are illustrated later on under the head of Retaining Walls.

20. Wall Facings.—Areas that are used principally by the public as a means of access to basements, frequently require that the walls be made especially attractive in appearance, consequently they are often faced with dressed stone, plain, glazed, or enameled brick or tile, or with marble. In selecting materials for this purpose, light colors are preferable if it is desired to light the basement by means of the area, as they will reflect the light instead of absorbing it.

The facing materials should not be installed until the rough work of the building has been completed, as otherwise it may be chipped or broken. Facings should be securely anchored to the walls, and joints should be thoroughly filled with mortar to prevent water from entering between the facing and the backing.

21. Waterproofing.—Area walls erected in a soil that does not permit of a good drainage of water often require to be waterproofed on the side adjoining the soil to protect the wall from being injured by the moisture. The materials most effective for this purpose are coal-tar pitch or a cement when properly applied. The subject of waterproofing is treated of elsewhere.

22. Back Filling.—After the area walls have been completed, and the forms removed, if forms have been required in the construction, soil should be filled into all open spaces around the walls and tamped down until it is compact and solid. The surface of this filling should be formed with a slope to drain water away from the walls.

AREA STEPS

23. Materials.—The materials that are most commonly used for steps in areas are wood, stone, brick, and concrete. Iron and steel are sometimes used in areas that adjoin city buildings where the space is very limited. Marble in the form of slabs is sometimes installed on a masonry foundation or on a framework of iron or steel.

24. Wooden Steps.—Wood is often used for steps in areas that are protected by a covering, but it is not so durable a material as stone, brick, or concrete. In Figs. 16 and 17 is shown a covered area which has wooden steps. These are constructed by placing supporting members, called carriages, against the side walls of the area, as shown in Fig. 17 at *f*, and securing these carriages to the wall by means of spikes driven into the mortar joints. Strips of wood *g*, called cleats, are then fastened to the carriages. The treads *h* are then fastened to these cleats and the carriages. The material generally used for both carriages and treads is 2-inch dressed plank.

25. Stone Steps.—Stone is a most satisfactory material for steps of areas and is generally used in the best class of work. Fine-grained blue sandstone is used extensively for area steps, although any stone may be used that is sufficiently hard and dense so that it will not absorb water and will withstand the wear. Stones that form steps should be provided with good bearings, be set in good beds of rich cement mortar, and have all joints filled and pointed to keep water from entering into the step foundations and causing them to deteriorate.

In many cases stone steps are made sufficiently long to allow the ends to extend into the walls at each side and thus secure a bearing on the walls, in which case they must be set while the walls are being erected. They may be of such length, however, that they will fit neatly between the area and foundation walls and rest on bearings formed by projecting some of the wall stones, as previously described and shown in Fig. 14 at *j*. On such bearings, the steps may be set during the construction of the adjoining walls or after they have been completed. It is better, however, to set them later, as they will not be subject to damage during the erection of the building.

Stone steps that are 6 feet or more in length should be provided with a bearing wall for the middle of the step, as shown in Fig. 14 at *i*.

Stone steps may be of solid slabs, as shown in Fig. 23 at *a*, or they may be constructed, as in Fig. 24, with separate slabs to form the treads *a* and the risers *b*.

The solid stone steps are more expensive than those formed of separate slabs, but they are very desirable as they are more durable, stronger, and present a better appearance. Each stone should be of sufficient width to overlap the stone below at least 2 inches, and thus permit of bedding each stone with mortar along its entire length.

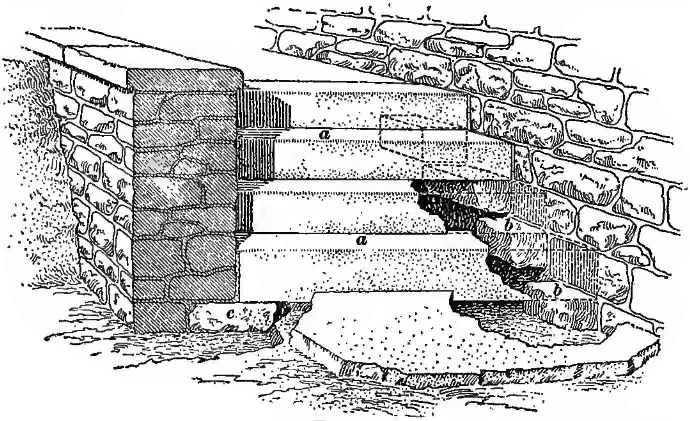


FIG. 23

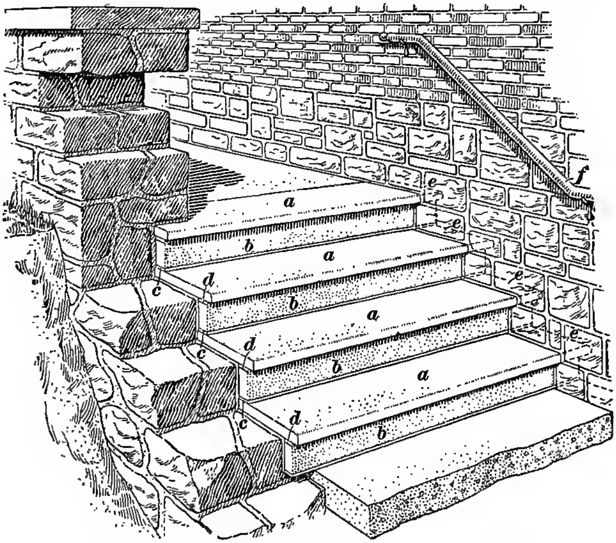


FIG. 24

In Fig. 23 the stone steps are set between the area walls and the foundation walls, and rest on stones which project beyond the face of the foundation wall, as shown at *b*, and beyond the area wall, as shown at *c*.

Slabs forming steps, such as shown in Fig. 24, should not be less than 2 inches thick and should be sufficiently wide to form a bearing for the riser at the back of the slab at *c*, and a nosing over the riser at the front of the slab at *d*. Steps of this character should be constructed while the walls of the area and building are being erected and the slabs should be extended into these walls, as indicated at *e*, to make them secure.

All stones forming treads of steps should be set with a slight slope downward toward the front to drain away water from the surface, and the edges of the steps should be slightly rounded. otherwise they may become chipped.

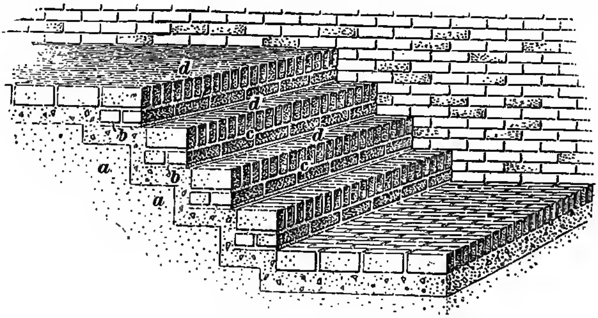


FIG. 25

26. Brick Steps and Brick Risers and Stone Treads. Steps formed entirely of brick, as shown in Fig. 25, or steps formed with brick risers and stone treads, as shown in Fig. 26, are often used for entrances to cellars of suburban residences.

Brick selected for these area steps should be hard burned so that they will not absorb moisture, especially when the steps are to be built in a locality that is subject to freezing weather, as otherwise they will deteriorate. Brick that have a slightly rough surface are preferred when used for the treads, to those that are smooth, as they afford a better footing and do not become slippery when wet.

Only rich cement mortar should be used in the construction of these steps so that the joints of mortar may also be impervious to moisture. Both brick and stone should be well bedded in the mortar and the joints carefully pointed with a trowel.

Brick steps may be constructed directly on the soil in localities that are not subject to freezing weather. The soil should be leveled under each step, as shown in Fig. 25 at *a*, to form a surface on which a bed of mortar or concrete *b* may be placed to receive the brick.

In localities having freezing weather, steps should be provided with a subbase of cinders, usually from 6 inches to 8 inches deep, as shown in Fig. 26 at *a*, and a base *b* of concrete about 4 inches thick, to form a foundation for the brickwork.

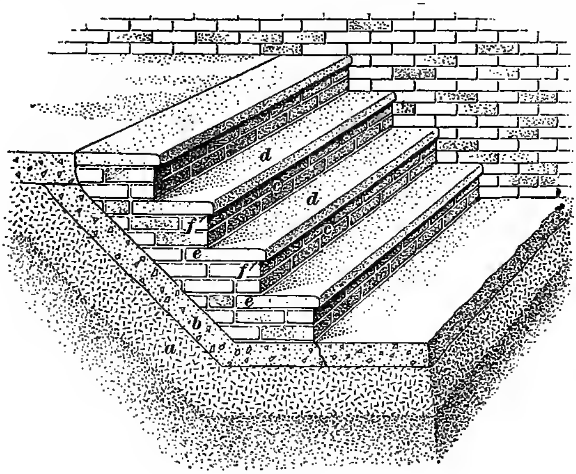


Fig. 26

The steps shown in this illustration are formed of brick risers and stone treads. Two courses of brick, which are laid on their flat face, form the risers *c*, and the treads *d* are of stone slabs of the same character as for the built-up stone steps shown in Fig. 24. These stone slabs should be of sufficient width to form a bearing for the brick riser, as shown in Fig. 26 at *e*, and a nosing over the brick riser below, as shown at *f*. All treads formed of brick or stone should be set to form a slope for the drainage of water from the surface, and the edges of the stone treads should be rounded as previously described for stone steps.

27. Concrete Steps.—Concrete is a very good material for area steps and is used extensively for the reason that sand, gravel, and broken stone are available in nearly all localities.

Concrete steps are made by erecting wooden forms of the size and shape desired for the steps and filling these forms with concrete.

In Fig. 27 is shown a form of construction where the entire flight of steps rests on a soil foundation. Excavations for these steps are made on a sloping plane, as shown at *a*, and on this plane a cinder bed or foundation *b* is installed to form a drainage for water, this being necessary for steps that are exposed to freezing temperatures, in order that no water may collect under the steps and freeze. In warm climates, and where the excavations are in sand or gravel, this cinder bed may be omitted. If the soil is not sufficiently firm to retain the sloping surface above described a wooden platform having a

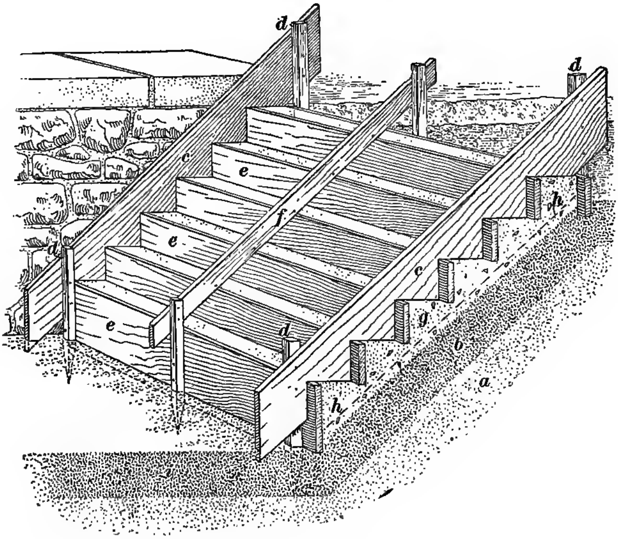


FIG. 27

similar slope may be installed to receive the cinders or the concrete base.

28. To construct these steps, forms must be provided for each step to hold the concrete at the various heights required. These forms are usually constructed with plank stringers, as shown in Fig. 27 at *c*. These stringers are placed at the sides of the area and held in place by means of wooden stakes *d*. The stringers are cut on the under side to the required shape of the steps, and boards or planks *e* are fastened to the stringers to form the risers of these steps. The boards *e* are usually reinforced at the center by means of a timber *f*, to which each board is securely nailed. This timber prevents the boards *e* from bulging out when the concrete is placed. Stringers should be located sufficiently high so that the concrete will extend beneath them and form a continuous slab of concrete under the entire flight of steps, as shown at *g*. This slab is usually reinforced with small steel rods or a coarse wire mesh *h*, which distributes the load throughout the slab and resists the expansion and contraction of the concrete which might otherwise cause the concrete to crack.

29. Concrete steps may be cast in their final form or in such a manner that a finishing coat of cement mortar may be applied after the forms have been removed. If a finishing coat is to be applied the treads should be made about 1 inch lower than the finished levels and the face of the riser should be formed about 1 inch back from the finished face as designed.

After these forms have been completed and the steel reinforcing rods have been placed, the concrete is deposited, the lowest step being poured first and then each step separately in order until the entire flight of steps is cast. While concrete is being filled into the forms the steel reinforcement should be raised slightly to make sure that it is entirely surrounded by concrete.

Concrete for this construction should have the various ingredients worked together so as to form a uniform mixture. Sufficient water should be added to wet all of these ingredients, but not enough to cause the mass to be so soft that the concrete will be pushed out of the lower part of the forms by the weight of the concrete that is placed in the upper parts.

30. When the concrete has set, the forms may be removed. If no final coat is to be applied the steps should be carefully examined and defective places repaired and the edges of the treads slightly rounded. This rounding may be accomplished by rubbing the edges with a piece of sandstone and keeping the concrete wet during the operation.

If a finishing coat of cement-and-sand mortar is to be applied to the steps, the repairing above described will not be required, as any roughness in the concrete will serve to help bond the concrete and surfacing mortar together. Before applying the surfacing mortar, however, the rough concrete should be thoroughly cleaned and wet with water so that the surface coating will adhere. It is customary to finish the surface of the treads somewhat rough to insure a secure footing, but the risers may be finished either rough or smooth as desired.

31. The flight of steps shown in Fig. 28 is of concrete that is reinforced with steel bars, as shown at *a* and *b*, and spans the distance between the soil bearing at *c* and the area-wall bearing at *d*.

The steps are constructed after the area walls have been completed, and require wooden forms on which the concrete may be placed and supported until the concrete hardens. These forms are left under the steps, as they cannot be removed after the concrete has been poured, but the decay of the wood will not affect the strength of the steps as they will be self-supporting when the concrete becomes hard.

The forms are constructed as follows: The posts *e* are placed at the top and the bottom of the flight, and on these are placed the timbers *f*, which run parallel with the sloping steps. The ends of these timbers are nailed to the posts. Crosspieces *g* are fastened to these timbers and the boarding is placed on the cross timbers as shown at *h*. Wedges *i* should be provided and placed under the posts *e* to permit of proper adjustment of the forms to the lines desired. The forms that are required to make the treads and risers of the steps and the manner of forming these steps are similar to those described for the steps shown in Fig. 27.

The surface of these treads may be made rough to secure a safe footing, or metal plates that are made of a material that affords such a footing may be installed as shown at *j* in Fig. 28. These plates should be set flush with the surface of the tread.

All concrete steps that are constructed in hot weather should be kept moist for several days after the forms have been removed and those which have a special finishing coat should also be similarly treated after the coating has been applied.

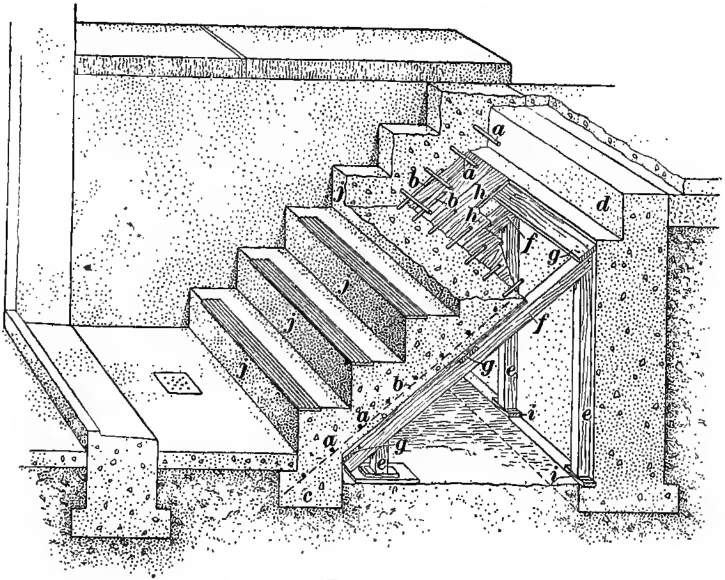


FIG. 28

32. Marble Steps.—Marble selected for steps should be of a variety that is hard and dense and free from seams that may open and permit water to penetrate the slab. The treads should be not less than 1½ inches in thickness and if they exceed 4 feet in length should be at least 2 inches thick. Risers may be 1 inch in thickness if so desired. Marble for this construction is usually finished with a smooth dull surface.

The marble slabs are usually assembled and installed in the same manner as thin slabs of stone. The ends of the slabs, however, are not extended into the walls at the sides, but require masonry to be built to support them. The steps are not installed until after all structural parts of the building have been completed.

Marble treads are sometimes equipped with metallic plates, of the same character as described for concrete steps, to afford a secure footing, as marble treads become very slippery when they are wet. A hand rail, as shown in Fig. 24 at *f*, is sometimes installed on a wall adjoining such steps to be used as an additional safeguard.

Marble steps require to be very carefully constructed and must be secured to the foundations in the most thorough manner to insure their permanence. Each slab should be carefully bedded in mortar to secure a level and even bearing, otherwise the slabs will break.

Marble slabs used for treads of iron stairs usually rest on metal shelves that are formed on the stair frames, and the slabs may be bolted to the metal work or cemented in place.

33. Iron or Steel Stairs.—Stairs made of iron or steel are usually constructed with treads and stringers but no risers, and the treads are finished with a rough surface to secure a safe footing, or metal plates as previously described are attached for this purpose.

AREA FLOORS

34. It is the usual practice to install floors in all uncovered areas to protect the foundations of the area walls and to keep the walls of the building dry. In areas designed as a means of access to basements the floor also forms a pavement between the area steps and the entrance door, as shown in Fig. 10 at *e* and in Fig. 14 at *c*.

Floors of areas in front of basement windows should be below the window sills, and floors of areas used as entrances to basements should be similarly placed below the door sills.

All area floors should be formed with a slope that will cause the water to flow to the opening in the floor provided for drainage, as shown at *e* in Fig. 8, at *f* in Fig. 10, and at *d* in Fig. 14. Areas that have a sand or gravel foundation frequently have the floor omitted, as these materials afford a natural drainage for the water. Floors are also frequently omitted in covered areas of the type shown in Fig. 16, except where the soil is of a character that prevents water drainage, when a floor will be required.

Excavations for floors should be made to the depths necessary for the foundations and the floor construction. If the soil is dense and water does not drain away freely, a 6-inch bed of cinders or gravel should be installed to provide drainage that will protect the floor. Area floors are usually constructed with a concrete foundation and a surface of cement-and-sand mortar. These floors are durable and impervious to water and are also easily installed. Brick and stone were formerly used very extensively for area floors, but these materials have been supplanted by concrete, except in localities where the stone or brick are more easily obtained than sand or gravel.

The construction of area floors of brick, stone, or concrete is the same as that required for the construction of sidewalks, which is described later on in this Section.

If marble or tile is used for an area floor, a concrete foundation not less than 4 inches thick should be installed on which a cement mortar should be spread to receive the floor material. All joints between the marble slabs or tiles should be filled with the mortar.

AREA DRAINS

35. The purpose of the area drain is to carry away the water from the area floor. This drain usually consists of a receptacle, which collects the water, and drain pipes which connect this receptacle with the drainage system of the building.

In large areas, such as shown in Figs. 8 and 10, where considerable water enters during a heavy rainfall, the receptacle usually installed is of the type shown in Fig. 29, which is called a *catch basin*. This basin is sometimes made 2 feet or 3 feet in depth, and thus forms a reservoir where the water may collect before it enters the drain, and it also permits sediment to collect which might otherwise enter the drain and cause a stoppage in the pipe.

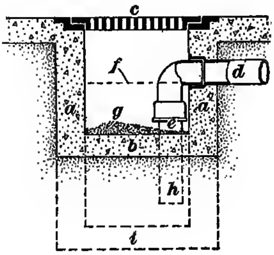


FIG. 29

These catch basins are constructed with walls *a* which are usually of masonry or concrete, and a floor *b* of concrete, and the entire basin is so constructed that it will hold the water. The top of the basin is provided with a cast-iron frame and movable grating *c*, to give access to the basin when required to clean out the dirt that collects on the bottom. The drain outlet *d* is placed near the top of the basin and the inlet into this pipe, as shown at *e*, is located near the bottom. This inlet should be a sufficient distance above the floor to allow the sediment to collect and also to permit some water to remain in the basin and thus form a seal that will prevent sewer gas escaping from the sewage system of the building. The dotted line *f* shows the level at which water will stand in the catch basin.

If the catch basin is deep, as indicated by the dotted lines at *i*, it will be necessary to extend the inlet pipe to *h*, allowing a space below the end of this pipe as described above.

36. As the water in the basin may evaporate during the summer months, however, and thus permit sewer gas from the house sewage system to escape, the plumbing regulations of cities usually require that the discharge line from the area drain be connected into a rain leader, behind the leader trap, as this trap, being quite large, will hold sufficient water at all times to form the seal necessary to prevent the escape of the sewer gas. A

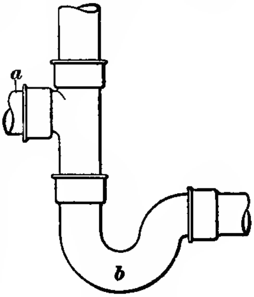


FIG. 30

leader of this character is shown in Fig. 30, the catch-basin drain entering it at *a*. The leader trap is shown at *b*.

Cesspools, such as are shown in Fig. 31, may be used as receptacles in small areas. These cesspools are usually made of cast iron and can be obtained in various sizes. They are provided with a hinged or movable grating *a*, to permit of cleaning out the dirt that collects at *b*. In some cities the plumbing regulations permit drains from cesspools to discharge into the sewage system of the building provided the connection is not less than 4 inches in diameter and a separate trap *c* is installed below the cesspool to form the water seal.

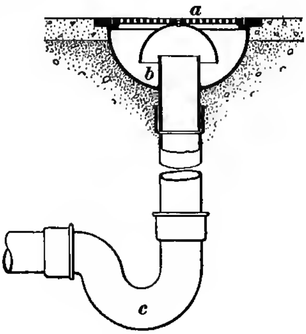


FIG. 31

BALUSTRADES, RAILINGS, GRATINGS, AND COVERS

37. Balustrades and Railings.—Large deep areas are usually enclosed with a balustrade of the form shown in Fig. 8 at *f*. The posts of these balustrades are usually made of cast iron. The rails and balusters are made of plain rolled steel shapes, or of cast iron when an ornamental design is desired.

A railing of the form shown in Fig. 14 at *e* is most commonly used for enclosing areas that provide a means of access to basements. This railing is formed of pipe cut to required lengths and put together by means of special fittings. The pipe used for the posts is usually slightly larger than that used for the rails.

All posts of cast-iron balustrades and pipe railings should be set into the coping and wall to a depth of at least 6 inches, and should have melted lead run around them to fill the remaining part of the opening in the stone so as to form a secure installation.

38. Gratings and Covers.—Small window areas are usually equipped with a grating as shown in Fig. 19 at *e*, although a railing may be used if so desired. These gratings are usually made in one piece, but if the area is large and it is desired to have access to it, the grating may be made in sections, which are hinged to the frame as shown in Fig. 22 at *c*.

Hinged gratings of this character are sometimes used for sidewalk areas where not prohibited by the local building code, but as these gratings permit dirt to pass through them, the areas become unsanitary and for this reason solid doors should be used. The covering shown in Fig. 32 has doors *a* formed of sheet steel, finished with a rough top surface so that pedestrians may not slip on them. These doors are hinged to an angle-iron frame *b*, which is securely fastened to the sidewalk. They are also provided with chains *c* or some other device that will hold the door open and in such a position that the doors will form the necessary protection at the sides of the opening. The front of the opening usually has a guard chain *d* which can be connected across the opening at the front edges of the doors when they are open, as indicated by the dotted chain. The doors and hinges are designed to be flush with the surface of the sidewalk when installed.

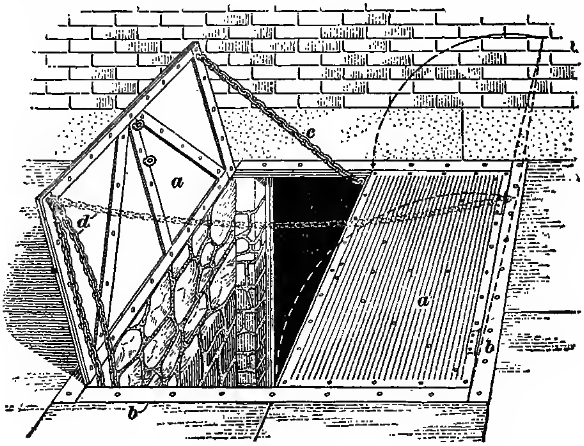


FIG. 32

39. In suburban districts, areas that are used for entrances to basements or cellars are frequently covered with wooden doors, as shown in Figs. 16 and 17. Such a covering is called a **bulkhead,** and is constructed with a wooden frame *a,* Fig. 16, which is securely fastened to the plates *d,* Fig. 17; and a headpiece *c,* Fig. 16, is provided to keep out the rain and snow and also to receive the top edges of the doors *b.* The doors should be of tongued-and-grooved boards securely fastened to battens *d,* and should have strong strap hinges and a padlock for fastening.

VAULTS

SIDEWALK VAULTS

40. Definitions.—In large cities where land is expensive and space is consequently valuable, the cellar or basement of a building is often extended beyond the lot line on the street front in order to utilize the space under the sidewalk. This extra space is called a **sidewalk vault,** or a *vault.*

The vault usually extends to the line of the street curb and also to the depth of the basement of the building. Buildings having a subbasement usually have a vault that extends to the floor of this subbasement and the vault is divided into stories to correspond with the basement and subbasement of the building. Sometimes the basement floor of the vault is omitted and the vault is used as a shaft for the purpose of lighting and ventilating the subbasement.

41. Building Laws.—In nearly all cities the construction of vaults under sidewalks is permitted. The building codes usually require, however, that the walls of the vault be constructed of stone, brick, or concrete, and be designed to be amply strong to resist the pressure due to the adjoining soil. The roofs are required to be of incombustible materials, and amply strong to carry the loads that they are to bear. Suitable openings must be formed in the roof, and devices installed in these openings whereby the vault may be ventilated.

There are some special requirements relating to vaults that apply only to certain localities, and the architect or contractor should familiarize himself with the local building code and these local requirements before preparing his plans and specifications, in order that the work may be designed to conform with the law.

42. Description and Uses.—Sidewalk vaults may be entirely enclosed by walls, the foundation wall of the building separating them from the basement, or they may be almost entirely open on the side toward the building and thus form an extension of the basement.

A vault that is practically enclosed is shown in Fig. 33. The wall that separates the vault from the basement is shown at *a*, an opening that permits of access to the vault is shown at *b*, the wall that retains the soil and roadway in place at *c*, the roof construction with the finished sidewalk at *d*, and the floor at *e*. The wall *c* is sometimes called a retaining wall although it is not a true retaining wall since it is braced at the top by the sidewalk construction.

Walls at the ends of the vault are sometimes called end or side walls, and when a vault is separated from an adjoining vault by a single wall that is so located that one-half of the wall is on one property and one-half on the other property, the wall is said to be a *party wall.*

Vaults of this kind are generally used for the storage of coal or merchandise, or as a means of taking goods into the basement, consequently they are generally provided with a coal-hole cover and frame, as shown at *f*, hinged doors of steel or iron *g*, and sidewalk ventilators *h* to admit air to the vault.

43. A vault that is entirely open on the side toward the building is shown in Fig. 37. The piers which support the upper portions of the building, as shown at *a*, form the only obstruction between the vault and the basement. The curb wall at *b*, the sidewalk at *c*, and the floor *d*, each serve a purpose similar to corresponding parts of the vault previously shown.

Vaults of this character may be used for any purpose to which the basement of the building is devoted, and the vault is usually finished in a manner that will correspond with the basement.

Sidewalk vaults of office buildings are frequently used for some part of the mechanical equipment of the buildings, such as motors and pumps that supply water to the plumbing fixtures, motors that operate the vacuum sweeper system, or for the sidewalk lifts and elevators.

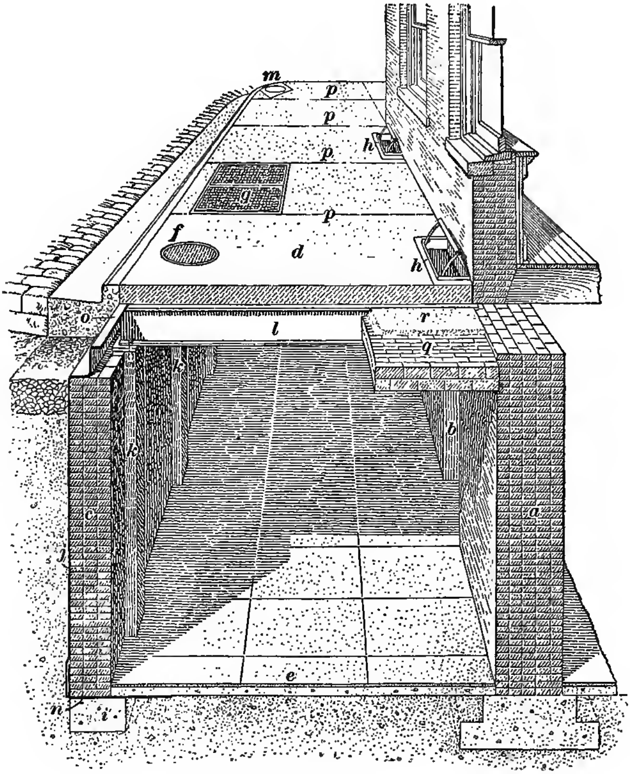


Fig. 33

In mercantile buildings where the basement is frequently used for the sale of merchandise, ventilators of the type shown at *e*, and sidewalk lights as shown at *f*, are installed to provide air and light for the vault and the adjoining parts of the basement, thus making the vault a most valuable addition to the floor space of the basement.

In this illustration, a part of the basement is devoted to the heating apparatus and a part of the vault to the storage of coal. The heating boiler is shown at *g*, the coal hole in the sidewalk at *h*, the coal bin at *i*, a fireman's ladder at *j*, and small doors in the sidewalk at *k* for access to this ladder, this being required by some codes to provide means of exit from the basement in case of fire. At *l* are shown sidewalk doors through which ashes may be removed from the basement by means of a sidewalk lift or a crane.

WALLS OF VAULTS

44. Excavations.—In making excavations for vaults, sufficient space should be provided not only for the walls and footings, but also to perform other operations, such as bracing the soil, pointing and waterproofing the wall. If the soil is not firm, braces consisting of strong timbers and plank should be installed to prevent the soil surrounding the excavated space from breaking away and falling. This bracing is of the greatest importance if the vault is to extend to the curb line, as the breaking of the roadway and the soil beneath it may injure municipal gas and water pipes that are frequently located adjacent to the curb and thus cause serious damage.

45. Construction.—Walls of vaults are built of stone, brick, plain concrete, or reinforced concrete, the choice of material depending upon what is most easily available in the locality where the vault is to be built, its cost, and sometimes upon the material which is used in building the foundation walls of the building. If the walls are of brick or stone, they should be laid in cement mortar. The materials should be well bonded together, the joints and crevices thoroughly filled, and the face of the mortar joints carefully pointed to prevent water entering the wall. If the wall is of concrete, both faces should be finished smooth and free from openings or pores through which water might enter.

It is the general practice to provide footings under all vault walls except where the soil is very hard or where rock is encountered. The size of the footing should be determined by the bearing value of the soil, a larger footing being required on a soil that is soft than on one that is hard and compact. These footings may be formed either of large flat stones or of concrete, the material used in the wall usually governing that used for the footing.

46. The curb wall shown in Fig. 33 at *c* has a footing *i*. This footing is located below the bottom of the floor slab so that the waterproofing material *j* may connect with the waterproofing under the edge of this floor slab as shown.

This curb wall is reinforced by means of pilasters *k*, and the top of the wall is braced against the wall of the building by means of the vault roof beams, one of which is shown at *l*. Walls that are reinforced and braced in this manner need not be so thick to resist the lateral pressure of the adjoining soil as walls that have no piers or braces.

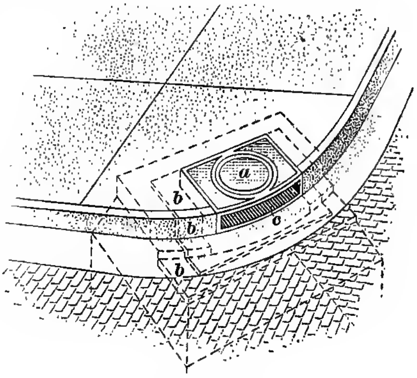


FIG. 34

47. In Fig. 33, the cover of a catch basin, which is located at the intersection of two streets, is shown at *m*. As the vault walls must be constructed in a special manner to receive a catch basin, details of the basin and its relation to the vault walls are shown in Fig. 34. The cover of the basin is shown at *a*, and the dotted lines *b* show the cast-iron frame, which rests on the masonry walls of the basin and is concealed under the sidewalk. As *c* is shown the inlet where the water enters the basin. Some cities have standard sizes for the various parts of these catch basins, and the architect or contractor should secure the necessary information from the proper authorities that will enable him to determine the correct size and dimensions for the recess that is required to be formed in the vault walls in which the basin is to be set.

48. The vault shown in Fig. 35 is similar to the one shown in Fig. 33, inasmuch as it is separated from the basement of the building by a wall *a,* in which there is an opening *b,* for access to the vault. In this figure is also shown a curb wall at *c,* a sidewalk at *d,* and a floor at *e.* The curb wall, however, is reinforced by means of steel I-beam columns *f,* instead of brick pilasters.

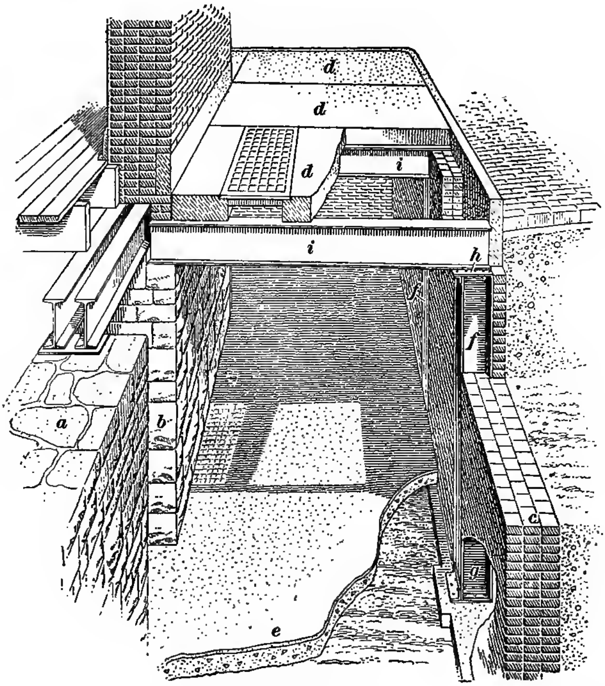


Fig. 35

In the construction of this wall the steel columns are set back from the outer face of the wall about 4 inches so that a course of brick may be installed to protect the face of the column. The foot of the column has a base *g* that is anchored to the footing of the wall by means of bolts, and the top of the column is secured to the roof beams *i* at *h*. In this form of construction the brick wall is reinforced by the steel columns and thus resists the pressure caused by the adjoining soil. The anchoring of the column to the footing of the wall prevents any slipping of the column at the bottom, and the top of the column is braced by the sidewalk beam *i*.

Curb walls of this construction are often used for vaults that extend to the depth of the subbasement of a building, the sidewalk beams *i* and curb-wall columns *f* being usually spaced about 4 or 5 feet apart. In Fig. 36 the wall columns are shown at *a*, and the walls are in the form of arches *b*. For these deep vaults, however, additional steel-beam braces, similar to the roof beams *i*, Fig. 35, are usually required. They are placed at the level of the basement floor and at the bottom of the curb-wall columns, opposite to the steel columns of the building, to resist the excessive pressure due to the high bank of soil that the wall has to retain in place.

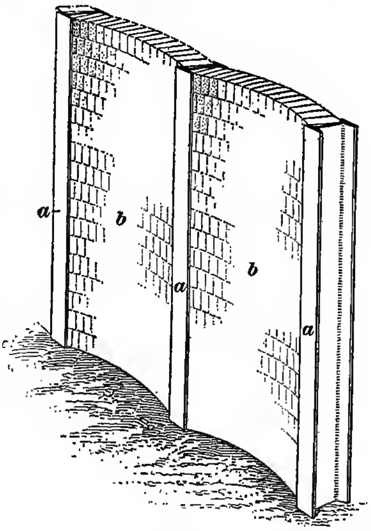


FIG. 36

49. In Fig. 37, the curb wall is shown to be made of plain concrete and is formed with a sloping inside face. A city fire hydrant is shown at *m*, the lower portion of which is installed in a recess formed in the curb wall. These recesses are required by the building codes of some cities in order that the hydrant and all pipes and fittings may be accessible from the roadway. Details, showing one form of construction of the curb wall at this hydrant, are shown in Fig. 38. In (*a*) the vertical section through the recess is shown at *a*, the space around the hydrant being filled with soil after the water connections to the hydrant have been completed. At *b* is shown

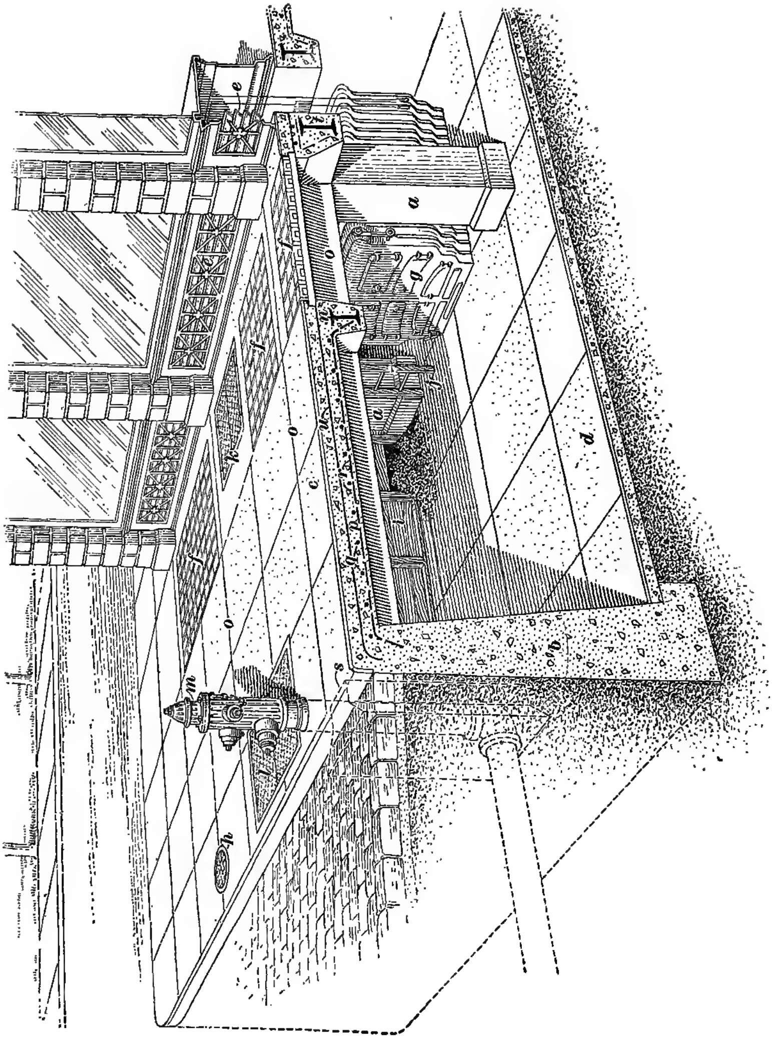


Fig. 37

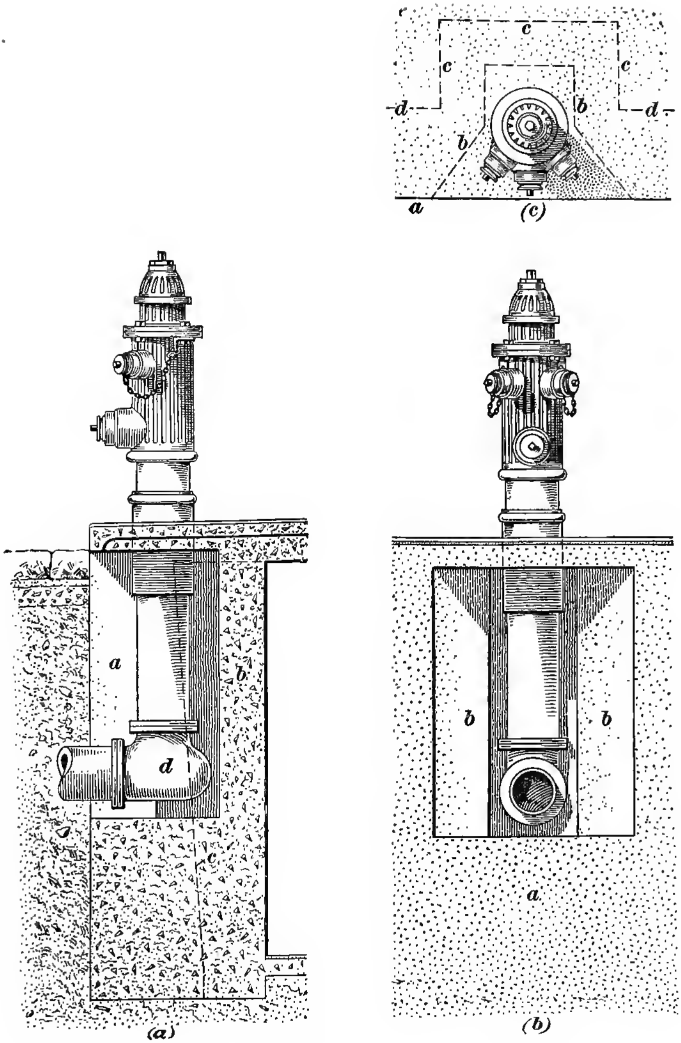


FIG. 38

the wall back of the recess, and the dotted line *c* shows the back of the regular curb wall at either side of the part which forms the enclosure for the hydrant.

A front view of the hydrant is shown in (*b*), the curb wall being indicated by *a* and the recess by *b*. A plan of the hydrant is shown in (*c*). The face of the wall is shown by the solid line *a*, the recess for the hydrant by the dotted line *b*, and the outline of the wall back of the recess by the dotted lines *c*. The regular curb wall either side of this specially formed part is shown by the dotted lines *d*.

The depth to which the recess is carried below the roadway will depend upon the climate of the locality where the work is to be done. The supply line to the hydrant and the valve that controls the water supply, which is located in the fitting *d*, in view (*a*), should be placed below frost line.

50. Waterproofing.—Frequently it is necessary to waterproof the outside face of the vault walls to insure the vault's being kept dry. This may be accomplished by coating the wall with hot pitch or by covering the wall and the footing with tarred felt, burlap, or other similar fabric, which is cemented to the wall by means of hot pitch. This latter method is shown in Fig. 33 at *j* and *n*. In both of these methods the wall coating of pitch should be applied in such a manner that all crevices in the wall are completely filled. If the felt or fabric is used it should be applied while the pitch coating is hot, to insure its adhering to the wall. The felt should overlap at the joints and these parts also should be cemented together by means of the pitch. This process is repeated with additional layers of felt until at least three thicknesses have been applied.

In this method of waterproofing it is customary to install the layers over the footing, as shown at *n*, before the wall is built, and these layers are made sufficiently long so that after the wall has been completed they may be turned up against the face of the wall and cemented in place. When the felt is applied to the face of the wall, as shown at *j*, it should overlap this footing covering, which has been turned up, and be thoroughly cemented to insure a waterproof joint of the two parts. At the top of the wall the felt should be carried up behind the curb to the level of the under side of the sidewalk slab, as shown at *o*, and be cemented to the part of the masonry back of the curb.

ROOFS

51. The roofs of vaults are of two types. One type has a framework of steel or reinforced-concrete beams, with panels of brick, tile, or concrete formed between the beams to serve as a foundation for the sidewalk.

The second type has a similar framework, but the sidewalk material spans the space between the beams and forms the roof of the vault.

A vault roof construction of the first-mentioned type is shown in Fig. 33. The framing consists of steel beams which extend from the curb wall to the foundation wall of the building, one beam being shown at *l*. Other beams of similar character are located at points marked *p*, and are spaced about 5 feet apart. These beams should be so set that they will slope toward the curb wall and be parallel with the sloping surface of the finished walk. In this illustration, brick arches are used between the beams to receive the sidewalk, a section through one of these arches being shown at *q*.

Hollow fireproofing tile is often used for arches between sidewalk beams and is a most satisfactory material for this purpose. When tile is so used, the beams may be spaced somewhat farther apart than they would be for arches formed of brick, as the tile is in larger pieces, is very light in weight, and is adapted to large spans.

In the construction of vault roofs of the brick or tile arch type, temporary wooden forms and supports will be required on which to place the roof materials, and these forms should provide suitable openings in the roof for the installation of ventilators, coal holes, door, etc. Only cement mortar should be used in the construction of brick or tile arches and the joints in these arches should be completely filled with the mortar and carefully pointed to form a suitable surface to receive waterproofing materials.

When plain concrete is used between the beams it is generally installed in the form of an arch on the under side while the top is formed level with the steel work.

A vault roof of the second type of construction is shown in Fig. 35. This roof consists of a framework of steel beams, as shown at *i*, and a sidewalk of flagstones *d* that span the distance between the beams. The beams should be accurately set both as to height and slope so that the desired levels for the sidewalk may be obtained. The construction of these sidewalks is more fully discussed later in this Section under the heading of Sidewalks.

52. Reinforced-concrete construction is sometimes used for a vault roof that has a framework of steel, as shown in Fig. 37. Parts of the steel frame are shown at *n* and *t*, and these beams connect with other beams at *o* that extend from the curb wall to the piers of the building. A roof slab which spans between the steel beams and on which the sidewalk is laid is shown at *p*, and the reinforcing bars of this slab are shown at *q* and *r*. In this illustration the steel beams are enclosed in concrete, which produces a very neat and finished appearance and protects the beams from fire. Reinforced-concrete beams may be used if so desired in place of the steel beams *n* and *t*. Their size and that of the steel reinforcement will be governed by the length of the beams between supports and the load they are required to carry.

53. Waterproofing.—Vaults of the type of construction shown in Figs. 33 and 37 often have the top surface of the roof waterproofed, as at *u* in Fig. 37, before the sidewalk material is installed, to prevent water entering the vault. The materials and the systems described for the waterproofing of the curb walls may also be used for treatment of the vault roof. The roof, however, should be carefully cleaned before the coating is applied.

FLOORS

54. Floors of vaults are usually made of concrete and are laid and finished to correspond with the floor of the basement of the building. Vaults that are used for the sale of merchandise or other purposes that require the public to use the vault often have floors of wood.

Concrete floors require a concrete bed on which is placed a top coat to form the desired finish. These floors are constructed and finished in the same manner as sidewalks, which are described later in this Section.

If a wooden floor is to be installed, there should be a bed of concrete laid on the soil to prevent moisture from entering into the wooden flooring and causing it to decay. This concrete bed should be from three to four inches in thickness, with the top surface leveled and partially smoothed. On this concrete, wooden beams, called *sleepers,* are placed. They are usually spaced 16 inches on centers and the flooring is secured to them.

SIDEWALKS

GENERAL DESCRIPTION

55. Definition and Purpose.—A sidewalk is a prepared footway placed at the side of a roadway for the use of pedestrians, and is usually separated from the roadway by a curb and gutter. It is generally finished with a hard, durable surface consisting of brick, stone, or concrete, and is formed with a suitable slope so that rainwater will run off it readily.

56. Building Laws.—As sidewalks are used extensively by the public, the building laws usually define the details of construction that are considered necessary to make them safe for the use of pedestrians. Some of the requirements that are common to many of the codes are the following:

Sidewalks over vaults shall be designed to be of sufficient strength to sustain safely the live load that they are required to carry.

Sidewalks shall be formed with a slope to drain away water. This slope shall not be greater than ¼ inch to 1 foot.

Sidewalks shall be formed with a rough surface that will afford a secure footing for pedestrians.

In addition to code requirements there are often city standards for the construction of sidewalks that also must be complied with.

57. Classification.—Sidewalks may be classified into two groups; those that rest directly on the soil or on a foundation which provides a uniform bearing throughout, and those which have bearings only at intervals and which are constructed of materials that will span the distance between these bearings and carry the required loads.

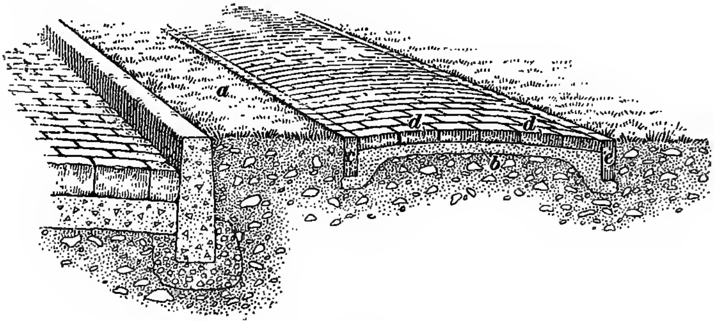


Fig. 39

Sidewalks of the first-mentioned class are illustrated in Figs. 33, 37, 39, and 40. In Fig. 33 stone slabs are supported upon a foundation formed by the brick arches *q* and the sand or concrete fill *r*. In Fig. 37 the sidewalk is of concrete placed on top of the waterproofing on the concrete slab below.

A sidewalk of the second type is shown in Fig. 35, where stone slabs of sufficient thickness and strength are supported on the steel beams and span the distance between the beams as well as support the superimposed load.

The widths of sidewalks vary according to the requirements of the locality where the walks are to be laid. In residential or suburban districts where there is very little traffic, the walks are usually made from 4 feet to 6 feet in width, and a space is often provided between the walk and the curb to form a grass plot, as shown in Fig. 39 at *a*. In business districts of cities, however, where there is a great amount of traffic, it is necessary that the walks be wide, and they are usually made to occupy the entire space between the curb and the building or lot line which they adjoin, as shown in Fig. 41.

CONSTRUCTION

58. Brick Sidewalks.—In residential or suburban districts and where the climate will permit of the use of a shallow bed of sand for a foundation, brick sidewalks are usually constructed as shown in Fig. 39. The excavations are carried to a depth of from 6 inches to 8 inches below the grade levels, and sand is placed in these excavations and leveled to form a uniform bed 2 inches thick, as shown at *b*, on which to place the brick.

At each side of the walk trenches should be formed below the regular excavations to receive the bricks set on end as shown at *c* and *e*. These bricks form a border for the walk and help to retain the bricks of the walk in place.

The bricks *d* should be so placed that there will be joints on all sides uniformly ½ inch wide. After all of the bricks of the walk have been placed, the walk is covered with sand and this is brushed into the joints until they are entirely filled, after which the superfluous sand is removed.

In this illustration the bricks are laid with the broad flat surface exposed. They may be laid, however, with the long thin face exposed, or some of the bricks may be laid flat and some on the thin edge to form a pattern if so desired.

When the soil adjoining a walk of this character is level instead of sloping toward the street curb, the sidewalk is usually formed slightly higher in the center than at the sides, to form what is called a *crown*, so that the water will drain toward each side.

59. In localities subject to freezing temperatures, brick sidewalks for residence districts should be constructed as shown in Fig. 40. In this illustration, the subbase of cinders which permits the water to drain away is shown at *a*, the concrete base at *b*, and the bed of cement mortar, which is to receive the brick, at *c*. Trenches which are partly filled with cinders are sometimes formed between the cinder subbase and the adjoining curb foundation, as shown at *e*, to carry away the water from the cinder foundation. Such trenches are called *leaders.*

The subbase of cinders, the base of concrete, and the trench between the walk and curb foundation are frequently omitted where sand or gravel are encountered in the excavations, in which cases the surface of the soil must be properly leveled to receive the cement bed for the brick.

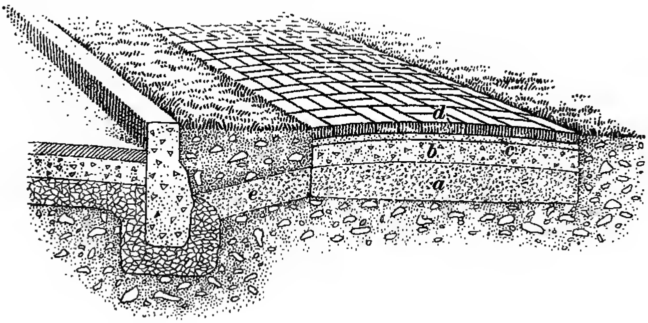


Fig. 40

The cinder subbase indicated is usually from 6 inches to 8 inches deep, although in extremely cold climates, and also where an excessive amount of water is encountered in the excavations, this base is sometimes made 12 inches deep. The concrete base is usually made about 4 inches thick and is formed of cement, sand, and gravel in the usual proportions. The cement bed for the bricks is made of cement one part and sand two to three parts, and is surfaced to the required levels by means of a straightedge used lengthwise of the walk. The leaders which drain the water away from the cinder subbase are usually located from 25 feet to 35 feet apart.

In the illustration, the bricks are laid on their broad flat face and alternate in direction to form a pattern. After the bricks have been laid in place they should be tested by means of a straightedge and bricks that are too high should be tapped lightly with a trowel to bring them to the position desired.

After the mortar in which the bricks are bedded has become sufficiently set to hold them in place, the joints between the bricks should be filled with a thin cement mortar, and the surface of this mortar pointed with a trowel. Before the mortar has become hard, mortar stains should be removed from the face of the brick by using water and a steel brush, or a brush made of strong vegetable fiber.

60. All brick sidewalks in business districts should have a concrete foundation and the bricks should be set in a cement mortar bed to insure their being retained in place. The joints between the bricks should also be filled and pointed as previously described. To lay sidewalks on the roof of a vault, cement mortar should be spread over the roof construction and the brick should be laid in this bed and be leveled to the line of a long straightedge that will span the entire width of the walk.

Sidewalks in the business districts are usually not formed with a crown, but slope downwards toward the curb.

61. Stone Sidewalks.—Sawed or split slabs of stone make an excellent sidewalk and are used extensively where such material is easily obtained. The best stone for this purpose and one that is most generally used is bluestone, although any compact limestone or granite will answer the purpose. The objection to granite, however, is that it wears very smooth and thus becomes slippery when it is wet.

Flagstone sidewalks for residential districts are usually formed of slabs that extend the entire width of the walk. These slabs are from 2 inches to 4 inches in thickness and the edges that are to adjoin are cut true and even to form close joints. The edges that form the sides of the walk are usually not dressed, but after the walk is laid they are cut to a line on the surface, the remaining part of the edge remaining rough.

Foundations for flagstone sidewalks are usually made of sand or cinders, and the depth of this foundation should be determined by the climatic conditions of the locality where the walk is to be laid. A very shallow bed of sand will suffice where there is no frost to affect the soil, but where cold weather occurs the bed should be from 4 inches to 12 inches deep to provide suitable protection for the walk. Leaders to drain away water from the cinder bed, as described for brick sidewalks, should be installed where possible.

62. Flagstone sidewalks for business districts are usually formed of large slabs so that there may be as few joints as possible. The slabs should be of ample thickness, as the excessive use of these walks causes the stone to wear away rapidly. Where these slabs form the roofs of vaults they are often made from 6 inches to 8 inches in thickness, this thickness being determined by the kind of stone that is used, the span between the bearings, and also by the live load the slab is required to carry. Walks of this character when resting on soil should have foundations similar to those described for residential districts.

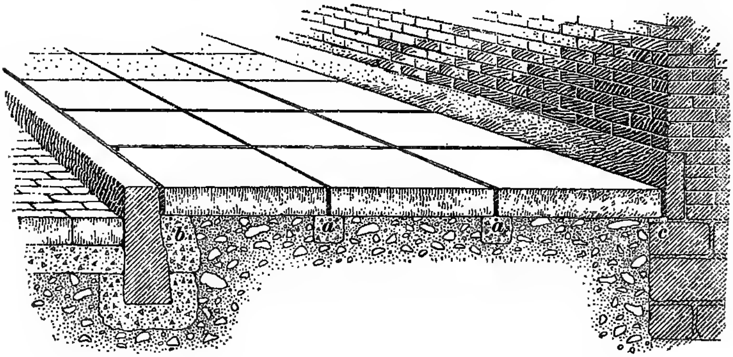


FIG. 41

Wide sidewalks which are formed of a number of slabs should be provided with foundations that will maintain the slabs in a level position at all times so that one slab may not project above or settle below the one adjoining and thus cause pedestrians to trip and fall. Slabs laid on the soil may be maintained in position by installing shallow concrete walls under each joint as shown in Fig. 41 at *a*. Slabs that adjoin the curb should rest on the curb wall where such a wall exists or on a shallow wall as shown at *b*, while those which adjoin the foundation of the building should rest on either the foundation wall, as shown at *c*, or a shallow wall similar to those installed at the joints.

63. Stone slabs for sidewalks when installed on a vault roof constructed as shown in Fig. 33 at *d*, should be provided with a bed of sand, as at *r*, on which the slabs may be placed. Sometimes concrete is used to fill over the arches and form this bed and also to secure a level surface on which waterproofing may be placed.

Stone slabs which rest on steel beams as shown in Fig. 35 require to be very carefully constructed to prevent the water from entering the vault below. These slabs should be of uniform thickness where they rest on the beam or wall to insure an even surface for the walk. Edges of the slabs should be cut true and even and the slabs set so that the joints will be uniformly ½ inch wide.

All joints between stone slabs, also the joints at the curb and wall lines, should be carefully filled with oakum and cement mortar. The process consists of placing oakum in the joint and driving it down by means of a hammer and a thin tool until it forms a compact filling to within 2 inches of the top of the slab. The remaining part of the joint is then filled with a mortar that is rich in cement. Hot asphalt, or asphaltic cement, is sometimes used in place of the cement for the filling, but it does not have the wearing value of the cement and will require to be replaced every few years if these joints are to be kept waterproof.

64. Plain Concrete Sidewalks.—All plain concrete sidewalks are usually provided with a cinder, gravel, or broken-stone subbase except those which are formed on a vault roof construction. The thickness of this subbase, however, may vary from 3 inches to 12 inches, depending upon the climatic conditions in the locality where the walk is to be laid, the greater thickness being required in very cold climates.

Excavations for sidewalk foundations should be uniformly level. If soft places are encountered, the soft soil should be removed and the space filled with the subbase material or good soil. If soil is used it should be tamped down until it is uniformly hard and level.

Concrete sidewalks over vault roofs are laid directly on the roof construction.

Where local building laws or city standards do not define the requirements for the construction of sidewalks, the following may be used:

Concrete for base of sidewalks should consist of one part of Portland cement, three parts of sand, and five parts of gravel or broken stone.

The gravel or broken stone should be of such size that it will pass through a screen having a mesh of 1½ inches in diameter. The base should be 4 inches in thickness.

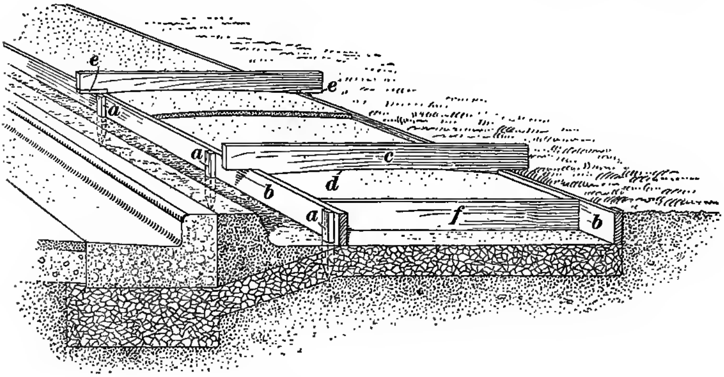


FIG. 42

The surfacing or top of sidewalks should be composed of one part of Portland cement and two parts of sand or clean sharp crushed granite or flint rock. This coating should be 1 inch in thickness.

Sidewalks should be laid off in blocks from 4 feet to 6 feet square, and the joints between these blocks should extend through both the top and the base.

65. All concrete sidewalks require *forms,* of wood or metal, to secure the desired shape and size. The tops of these forms are used as guides for the straightedge or templet when the surface of the sidewalk is being formed.

Sidewalks that are not confined between a street curb and the wall of a building require forms of the type shown in Fig. 42. These are constructed by driving stakes *a* securely into the soil and securing the side pieces *b* to these stakes after these members have been properly leveled and straightened. These forms should project slightly above the level of the soil adjoining the sidewalk. Materials that are to form the concrete should be carefully proportioned and thoroughly mixed while dry, the water then added and the materials again mixed until the mass assumes a uniform color and is sufficiently plastic so that it can be tamped but will not flow. This concrete is then placed on the subbase and tamped by means of a rammer, one type of which is shown in Fig. 43 (*a*), until the surface is approximately smooth and at the level desired. The board or templet *c*, Fig. 42, which has been formed with a running edge and curved to the shape of the crown for the sidewalk, is then drawn back and forth over the concrete to secure the exact lines and surface desired.

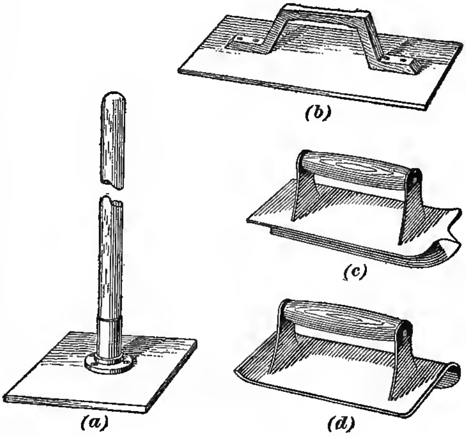


FIG. 43

Joints between the concrete blocks are usually formed by means of a thin wooden or metal cross-form, as shown at *f*, which is located in the position desired before the concrete is deposited. The wooden cross-form may be held in place by means of stakes, or preferably may be secured to the side forms in such a manner that it can be easily removed when required.

When the concrete base of two adjoining blocks has been completed, the cross-form is removed and the joint that has been formed by the removal of this form is filled either with sand or felt paper or some similar material to preserve the joint during the process of applying the top coat. The location of these joints should be marked on the top edge of the forms so that the joints in the top coating may be located directly over those in the concrete base. Joints in sidewalks are sometimes formed by completing every other block of concrete and, when this concrete has set, removing the cross-forms and installing concrete in the intermediate panels. A walk that is being constructed in this manner is shown in Fig. 44. The panels *a* have been completed and the cross-forms *b* are still in place. Forms are also in position for the concrete to form the panel *c*.

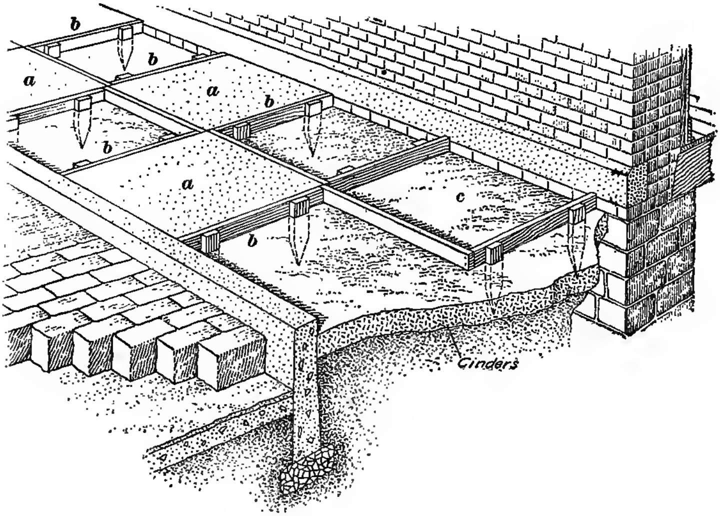


Fig. 44

This method of construction permits of access to all sides of each panel, which facilitates finishing both the edges and the surface.

Sidewalks that are likely to be exposed to extreme heat or cold should have some of the joints between the blocks made from ½ inch to ¾ inch wide to permit the concrete to expand and contract. These joints are called expansion joints and are usually located about 50 feet apart in the length of the walk. Expansion joints in wide sidewalks of the business districts of cities are usually provided at the curb and the building line in addition to those mentioned and these joints are filled with asphalt or an elastic cement that will prevent water entering the vault through these places.

66. The top of the sidewalk should be applied as quickly as possible after the base has been finished. If the base has become dry, as it is likely to in hot weather, there is no assurance that the top will bond with the base unless every precaution is taken when placing it. The method usually adopted to obtain this bond is to wash the concrete base thoroughly with water and apply a thin coat of cement mixed with water, then apply the top surface on this while it is still wet.

The top coating is usually tamped, then leveled and smoothed with a templet similar to that used for smoothing the concrete base. The same templet may be used if desired, by adding blocks, as at *e*, Fig. 42, to the running edges to raise the templet to the desired height. This templet is drawn back and forth over the surface; additional surfacing material is deposited as required and the templet is operated until the entire surface of the sidewalk has been brought to the levels of the wooden grounds. When this has been completed, the surface of the sidewalk is treated to produce a smooth or rough surface as desired.

67. Concrete sidewalks are usually finished by means of a wooden trowel as shown in Fig. 43 (*b*), or a coarse brush, as these tools will produce a somewhat rough surface. A sidewalk finished with a metal trowel will be very smooth and become slippery in wet weather and consequently dangerous to pedestrians.

Joints in the top coating should be made directly over those formed in the base so that cracks due to settlements, contraction or expansion will not run across the panels, but will develop at these prepared joints. These joints are finished by means of a tool called a *groover*, shown in (*c*), which also forms a neat border line near the joint.

The edges of the sidewalk adjoining the wooden forms are usually finished with an *edger*, shown in (*d*). This tool forms a round edge and also a border that is similar to that formed at the joints.

68. Coloring matter, such as lampblack or other mineral pigment, is sometimes mixed with the top coat to secure a desired color; the proportion generally used is from ½ pound to 4 pounds of the dry color to 100 pounds of the dry cement. This is based on the use of mortar that is composed of one part of cement to two parts of sand. The use of greater proportions of color to the cement than noted above is not advisable, as it is likely to prove injurious to the mortar and prevent it from becoming sufficiently hard to be effective.

Sidewalks that are laid in hot weather snould be covered with canvas as soon as completed, to shield them from the sun's rays, and thus permit the cement to set slowly. This covering should be removed at intervals and water applied to the sidewalk to keep the concrete damp for a period of two or three days.

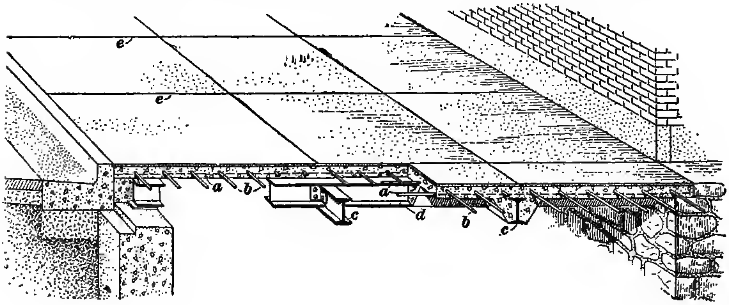


FIG. 45

69. Reinforced-Concrete Sidewalks.—Concrete sidewalk slabs that are required to span spaces between bearings are reinforced with steel. Rods are sometimes used for this purpose, as indicated in Fig. 45 at *a* and *b*, although heavy expanded-metal lath or other form of steel may be used. The bearings in this illustration consist of the curb, the foundation wall of building and steel beams. The steel beams *c* are placed parallel with the wall of the building and are supported by other steel beams that extend from the curb wall to the building wall. Part of one of these beams is shown at *d*, and others are located at points *e*. The steel beams are shown encased in concrete, but this is not a necessary part of the construction, as the reinforced-concrete slab extends over the top of the beams and rests directly on them.

The kind of reinforcement selected will depend upon the availability of the material. The thickness of the reinforcement will be determined by the weight of the slab and the live load that it is required to carry, also by the distance between the supports, or bearing points, that the slab is required to span.

Reinforced-concrete girders are sometimes used in this construction instead of the steel beams *c* and *d*.

The construction of the base and the top coating is similar to that of the corresponding parts of concrete sidewalks previously described.

The concrete base in this case is built upon forms that are supported by the beams and are removed after the sidewalk has fully set. The base, however, is not cut into squares nor are expansion joints formed as the steel reinforcement counteracts the contraction and expansion of the concrete. The top coating, however, may be cut into squares if so desired.

Reinforced-concrete sidewalks such as have been described are also built directly upon the soil with suitable beds of cinders beneath them. The reinforcement prevents the sidewalk from cracking, as it counteracts the effect of expansion and it also keeps the sidewalk from deflecting or sagging.

Curbstones and gutters for street roadways are usually installed under city contracts. When the owner of a property, however, erects a vault of the character shown in Fig. 37, the curb is usually formed as a part of the curb wall and the exposed edges of this curb will have to be provided with a metal member as shown at *s*, to protect this edge and withstand the wear due to vehicle traffic.

70. Asphalt Sidewalks.—Asphalt is sometimes used as a surfacing material for sidewalks. It is not suitable, however, for use in localities subject to extreme heat or cold, as the heat softens the asphalt to such an extent that the traffic disfigures and destroys the surface and the cold causes contraction cracks that permit water to enter into the foundation and thus cause the sidewalk to deteriorate.

The asphalt is prepared by heating in large kettles until it becomes a liquid, after which sand is added and mixed with the asphalt until the desired consistency is obtained. This is then applied to a concrete base similar in character to that described for concrete sidewalks.

The asphalt is tamped and rolled while hot until the desired surface has been secured and is usually about 1½ inches in thickness when finished. After the asphalt is rolled, dry cement is sprinkled over the surface and distributed with a broom.

SIDEWALK LIGHTS

71. Definition.—Sidewalk lights are panels or frames containing pieces of glass that are inserted or built into the pavement over a vault to permit of light entering the vault or adjacent parts of the cellar or basement. These lights are sometimes called *pavement lights* or *vault lights*.

Sidewalk doors, covers of ventilators, and coal-hole covers are often provided with these glass panels and thus serve as sidewalk lights.

72. Parts.—The parts of the sidewalk lights are the glass, either in the form of small sheets, or of lenses, and the frame or construction in which the glass is set. This frame or construction may be of metal or of reinforced concrete, and is formed with subdivisions that are of a suitable size to hold the glass.

73. Building Laws.—Building laws of cities usually define the character of sidewalk lights and the details of their construction. The following specifications cover the essential features that are considered necessary to make them safe for the use of pedestrians:

The construction shall be of a character that will be sufficiently strong to support the traffic that usually comes on the sidewalk.

The plain surfaces of glass and iron shall be of a limited area, as these materials become very slippery when wet and are consequently dangerous to pedestrians.

The top surface of metal, when so used, also of concrete when the frame is formed of this material, shall be finished rough or treated with a material of the character of carborundum to afford a secure footing.

74. Types and Uses.—There are two general types of sidewalk lights. One type has plain glass panels or plain flat lenses,* as shown in Fig. 46, that permit the rays of light to pass through them without being deflected. These will light only the portion of the vault directly below the sidewalk light and they are generally used to illuminate vaults that are enclosed on all sides by walls.

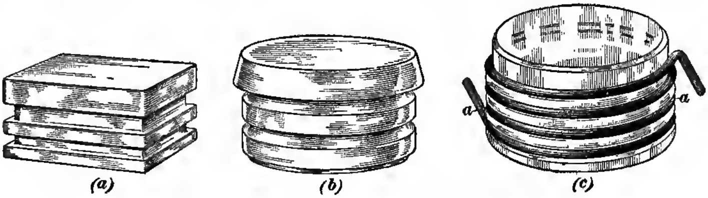


FIG. 46

The other type has lenses that on their under sides have sloping extensions, called *pendants* or *prisms,* as shown in Fig. 47, which cause the rays of light to be deflected as they pass through them. Such lenses are used in sidewalks over vaults that are open on the side toward the basement of the building and permit of illuminating both the vault and portions of the basement adjoining.

75. Lenses. — All lenses are formed of glass that is made especially for the purpose of sidewalk lights. It is the aim of the manufacturers to produce a glass that will retain its brilliance, toughness, and resilience, as these qualities are necessary to good service.

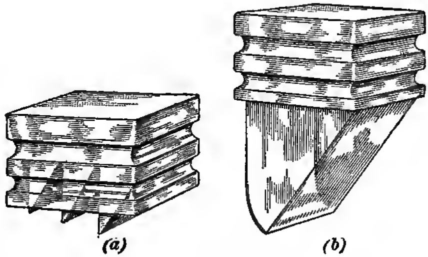
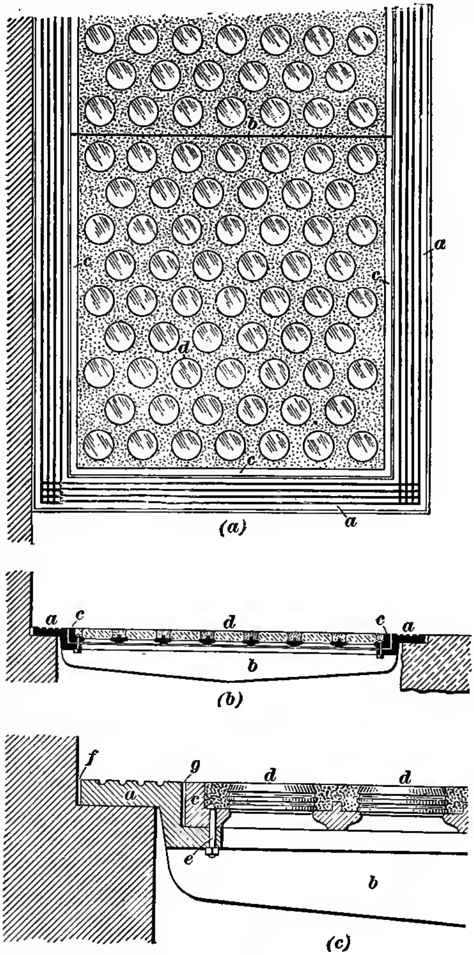


FIG. 47

---

*[*Flat lens,* as here used, is a trade term. Ordinarily, a lens must have at least one convex or concave face.

Lenses are made both square and round in form, as shown in Figs. 46 and 47. The edges of the lenses are made in many shapes, the one shown in (*c*) of Fig. 46 being so designed that



(a)

(b)

(c)

Fig. 48

it may be removed if it becomes broken and a new one put in its place without causing any damage to the concrete in which it is set. In this case the metal wire *a, a* is firmly held by the cement and forms a screw thread by means of which the lens may be screwed into place.

76. Construction.—Metal frames for sidewalk lights may be made of cast iron, steel bars, or sheet steel reinforced by means of steel bars of standard shapes. In Fig. 48 is shown a cast-iron frame of the type most generally used. In this illustration the plan is shown in (*a*), a section through the frame in (*b*), and a detail of the frame in (*c*). In all of these figures, the outside frame is indicated at *a*, the cross-ribs at *b*, the inner frames which form the panels at *c*, and the lenses at *d*. In (*c*) it will be noted that the outside frame has a shelf on which the inside frame rests and that these frames are fastened together by means of a bolt as shown at *e*. This connection is made before the concrete is filled around the lenses. The joint between the outside frame and the wall at *f*, and the joint between the two frames as shown at *g*, also the joint between the panels as shown at *b* in (*a*), should all be filled with an elastic cement.

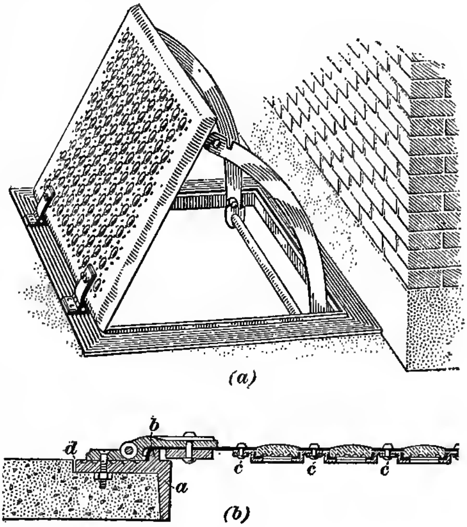


Fig. 49

77. In Fig. 49 (*a*) is shown a sidewalk door intended to admit both light and air into a vault. Lenses similar to those used in the sidewalk are placed in the door, and the door is equipped with hinges and an operating device that permits of the door being opened and closed from within the vault.

The frame of the door, shown at *a* in (*b*), is of cast iron, and on its top surface are grooves and an upward-projecting lip *b*, over which the edge of the door laps. The door is usually formed of No. 12 gauge sheet steel, and holes are cut in this plate where the lenses are to be located. Separate pieces of sheet steel *c* into which the lenses fit are attached to the under side of the door, and in them the lenses are placed and secured by means of a cement made of sulphur and tar. The joint *d* between the door frame and the sidewalk should be cemented in the same manner as described for other sidewalk lights.

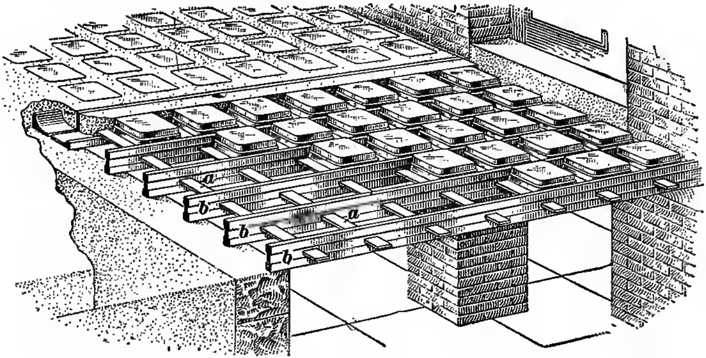


FIG. 50

78. Fig. 50 shows a steel frame built up of standard sections *a* and *b*. Spaces are provided for the individual lenses and cement mortar is poured between the lenses and over the steel supporting frame. In Fig. 51 is shown a sheet-metal frame that serves as a support, or form, upon which to cast the concrete. The lenses are put in place, the reinforcing rods *a* are placed as shown, and concrete is poured around the lenses and around the reinforcing rods.

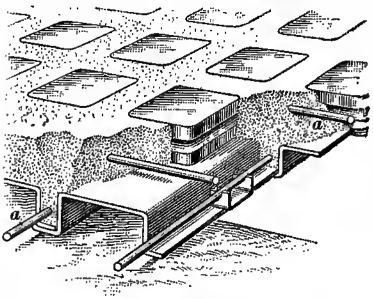


FIG. 51

In Fig. 52 is shown a construction formed of reinforced concrete which supports the glass lenses. This construction is built upon wooden forms on which the lenses and the reinforcement are placed. The concrete is then poured and fills the spaces around the lenses and the bars, forming a solid slab which is self-supporting after the cement has set. When the slab has become strong enough to support the required loads the forms may be removed.

79. There are various other forms of sidewalk lights, each having its own system of construction. Manufacturers of these lights usually suggest how their products should be assembled and installed.

Sidewalk lights for flagstone sidewalks are set after the stone slabs are put in place. Suitable openings in these walks must be provided and the top face of the stone adjoining the openings must be cut to form a recess so that the frame may be set flush with the surface of the stone.

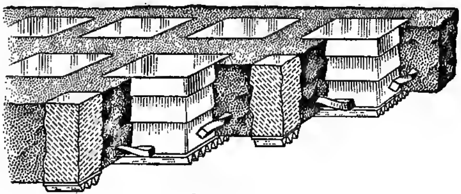


FIG. 52

The metal parts and the lenses of sidewalk lights that are to be formed in concrete sidewalks are usually assembled before the sidewalk is laid, and the concrete which encloses the lenses is installed at the same time that the sidewalk is formed.

Carborundum grit is sometimes mixed with the top coat of the concrete which is used to fill around the lenses, to form a surface that will afford a good footing for pedestrians. If this material is used, the concrete should be allowed to become hard before it is subjected to foot traffic, otherwise the grit may be torn away from the concrete.

RETAINING WALLS

DESCRIPTION AND PRINCIPLES

80. Definition.—A retaining wall is one that retains in place a filled-in backing of soil or rock, or holds in place a bank of gravel, sand, or soil that is not compact enough to retain its form when a vertical cut is made in the bank.

81. Types of Retaining Walls.—There are two types of retaining walls, each involving a different principle of design and requiring a different form of construction. One of these types depends upon the weight of the material of which the wall is built to resist successfully the lateral pressure from the soil and is formed of masonry or concrete to obtain this weight. Such walls are called *gravity walls*. One form of gravity wall constructed of stone masonry is shown in Fig. 53, while another form, made of concrete, is shown in Fig. 54.

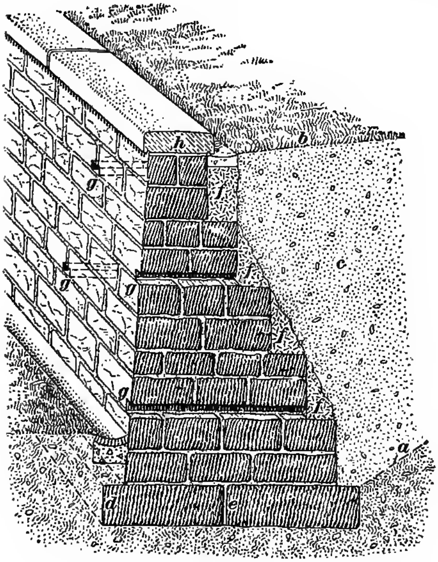


Fig. 53

The other type of retaining wall depends upon the form or shape of the wall, rather than upon its weight, to resist the pressure from the soil, and is designed to act as a lever, or what is known as a *cantilever beam*. From this fact it is sometimes called a *cantilever retaining wall.* This form of wall is constructed of reinforced concrete and is also called a **T** *type* of retaining wall on account of the inverted **T** shape that is formed by the wall and the base on which the wall rests. A retaining wall of this type is shown in Fig. 55.

82. Design.—The design of retaining walls is difficult and filled with uncertainties. Moreover, retaining walls, although carefully and elaborately designed, often fail. For this reason rules are used which are not based entirely upon mathematical calculations, but which depend largely upon experience.

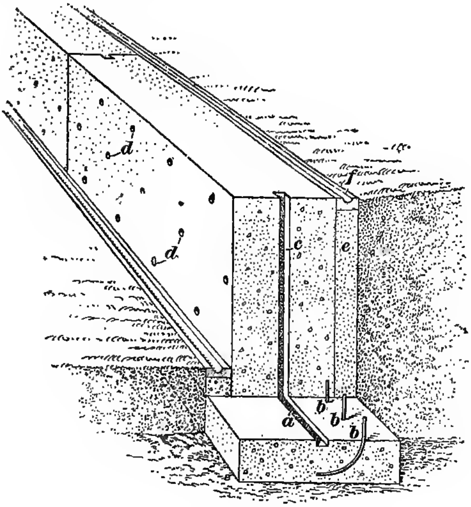


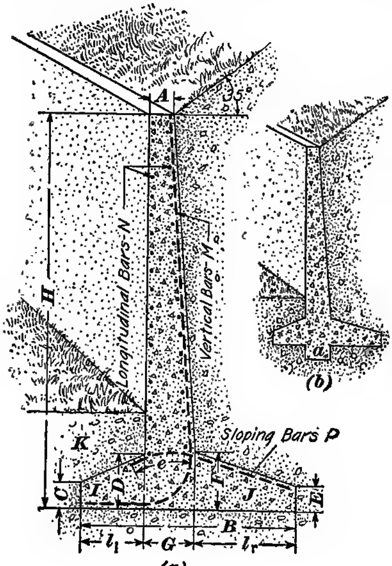
FIG. 54

Probably the best series of rules for designing gravity retaining walls that are to have the exposed faces vertical and to be of uniform thickness throughout their heights is that presented by John C. Trautwine in his well-known Civil Engineer's Pocket Book. These rules with slight modifications provide the following proportions:

The ratio of the thickness of a retaining wall to its entire height should be .35 for a wall constructed of cut stone or of first-class rubble of large sized stones laid in cement mortar; .4 for a wall constructed of good common rubble laid in cement mortar, good hard-burned brick laid in cement mortar, or a wall of plain concrete; and .5 for a wall constructed of good dry rubble.

For example, a retaining wall built of good hard-burned brick laid in cement mortar should have a thickness equal to .4 of its total height.

It is assumed that the wall has a foundation of masonry sufficiently large to secure a proper distribution of the load on the soil, also that the soil filling back of the wall is deposited loosely and leveled to line with the top of the wall. If the filling is tamped and thus made compact, the thickness of the wall may be slightly reduced. This reduction, however, is not usually made.



(a)

FIG. 55

83. In Fig. 56 are shown diagrammatically five designs that are frequently used for retaining walls. All of these designs require the same amount of material for the wall, the reduction in thickness in some parts being offset by an increase in thickness of other parts. No footings are shown in these designs, as they do not enter into the designing of the walls, but relate to the bearing values of the soil.

The diagram in (*a*) represents a retaining wall with vertical faces and a uniform thickness that is equal to .4 of its height. This diagram is used in designing the remaining four forms of walls and is modified as described.

The diagram in (*b*) represents a retaining wall with a vertical face and a sloping back. To design this wall, draw a rectangle equal to *a b d c* of diagram (*a*); locate the point *e* midway between *b* and *d* and locate the point *f* on the line *a b* at such a distance from *a* as is desired for the thickness of the top of the wall and draw the line *f e* and extend it to *g*, then extend the base line *c d* to *g* and the section *a c g f* will be that of a wall having the same sectional area as that in (*a*).

In (*c*) a wall with a sloping face and a vertical back is shown. For walls of this form the slope, or *batter*, is usually from 1 inch to 2 inches for each foot in height of the wall and is represented by the line *a e*, the total projection from the vertical line being represented by *c e*. For example, in a wall that is 12 feet high and has a face formed with a slope of 1 inch to the foot of height, the distance between *c* and *e* would be 12 inches. After the rectangle *a b d c* has been drawn and the slope of the face of the wall determined, locate *f* midway between *a* and *c*, also locate *g* midway between *b* and *d* and draw the line connecting these two points. Extend this line to *h* and lay off *h i* equal to *f g*. Draw the line *j k* through *i* and the section *a e j k* will have the same area as that in (*a*) and (*b*).

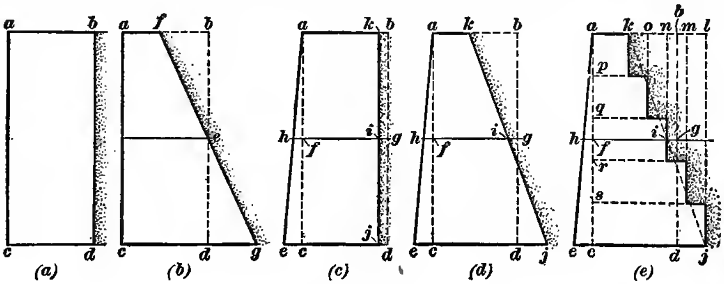


FIG. 56

In (*d*) the diagram represents a wall with a sloping back and also a sloping face. In designing this form of wall, the sloping face and the point *i* are obtained in the same manner as previously described for similar parts in (*c*). The thickness of the wall at the top is the same as shown in (*b*) and is represented in diagram (*d*) by *a k*. From *k* draw the line *k i* and extend this line to *j*, also extend the line *e d* to *j*, and the diagram *a e j k* will have the same area as that in (*a*).

The wall shown in the diagram (*e*) is of the same size as the one shown in (*d*) and is similar in shape, with the exception that the back of the wall has offsets, instead of a slope. To determine the form of these offsets, on a diagram similar to that in (*d*), draw a vertical line from *j* to *l*, as in (*e*), and divide the distance *l k* into an even number of equal parts, four parts being used in this illustration and shown by *l m, m n, n o,* and *o k.* Divide the height of the wall *a c* into equal parts, one more in number than the divisions of *l k,* as shown by *a p, p q, q r, r s,* and *s c.* Complete the diagram by drawing lines from the vertical and horizontal subdivisions to form the offsets as shown.

84. As a large majority of failures in retaining walls are due to defects in the foundations, it is of the greatest importance that this part of the structure be properly designed. The area of the footing should be determined primarily with reference to the bearing value of the soil. In determining the size of the footing, however, not only the weight of the wall must be considered, but also the pressure of the soil back of the wall.

In estimating the amount of pressure against the back of the wall it is customary to compute it as the weight of the soil that lies between the finished grade line and the natural slope of the soil, and to design the wall and footing to resist this pressure.

The natural slope may be defined as the line or plane along which the embankment of soil tends to slide. In Fig. 53 this is shown at *a,* the finished grade line at *b,* and the mass of soil which is producing the pressure at *c.*

The angle of the slope depends upon the character of the soil, the angle being less for sand and gravel than for more solid and compact soils.

The slope of the line *a* is 35 degrees above the horizontal, this being the angle usually assumed by engineers when estimating the pressure of the soil.

As the pressure of the soil against the wall tends to overturn the wall, the pressure of the wall on the soil upon which it rests is greater at *d* than elsewhere under the footing. On account of this variation in pressure, a low bearing value of the soil should be taken when designing the spread of the footings.

The weight of a wall of the gravity type is usually sufficient to prevent the wall from slipping on the soil. Like all other walls, however, the foundations should be carried below the grade level to such depth that they will not be affected by frost.

85. In the design of the wall shown in Fig. 55, the foundation *B* is spread out to secure a good bearing on the soil and prevent the wall from settling.

The projection of the footing in front of the wall, shown at *I* in (*a*), is called the **toe,** and the one at the rear of the wall, as shown at *J,* is called the **heel,** these projections being designed so as to prevent the wall from being overturned by the pressure of the soil back of the wall.

The principles involved in this design are that the pressure against the wall tends to turn the wall around the toe. The weight of the soil which rests on the heel together with the weight of the wall overcome the overturning tendency and hold the wall in place. Steel reinforcement is embedded in the wall and in the footing to supply the necessary strength so that the wall itself will not break.

In this figure, the steel bars *M, N,* and *P* are intended to prevent the wall from breaking. Those shown at *M* carry the tension due to the bending of the wall proper and are extended into the toe of the footing. The bars *N* are run longitudinally in the wall to prevent the concrete from shrinking and producing cracks. The bars *P* reinforce the heel of the footing and bond this heel with the base of the wall proper.

The weight of the wall and the soil which rests on the heel of the footing are usually sufficient to keep the wall from slipping on its footing. It is desirable, however, to extend the footing below the lower grade level sufficiently to permit the soil at *K* to form an additional resistance against this slipping. If the footing cannot be carried to this depth an extension may be formed on the bottom of the footing, as shown at *a* in (*b*). All walls exposed to freezing weather should have the footing carried to a point below the frost line.

TABLE I

DIMENSIONS AND REINFORCEMENT FOR T-TYPE RETAINING WALLS

For Meaning of Reference Letters, See Fig. 55

Item	Total Height	Length of Base	Length of Right Cantilever	Length of Left Cantilever	Upright Beam								Left Cantilever			
					Dimensions of Slab		Reinforcement						For Plain Round Bars		For Square Deformed Bars	
							Plain Round Bars M		Deformed Square Bars M		Plain Round Horizontal Bars N					
	H Feet	B Feet	l_r Inches	l_l Inches	Thickness at Top A Inches	Thickness at Bottom G Inches	Size Inch	Spacing Inches	Size Inch	Spacing Inches	Size Inch	Spacing Inches	Thickness at End C Inches	Maximum Thickness D Inches	Thickness at End C Inches	Maximum Thickness D Inches
1	8	4.00	20	18	6	$9\frac{1}{2}$	$\frac{1}{2}$	$4\frac{3}{4}$	$\frac{3}{8}$	$4\frac{3}{4}$	$\frac{1}{2}$	12	6	12	6	9
2	12	6.50	39	24	8	$15\frac{1}{2}$	$\frac{5}{8}$	$4\frac{1}{4}$	$\frac{1}{2}$	5	$\frac{5}{8}$	9	8	17	8	$13\frac{1}{2}$
3	16	8.75	50	31	10	$23\frac{1}{2}$	$\frac{7}{8}$	$5\frac{1}{2}$	$\frac{5}{8}$	$5\frac{3}{8}$	$\frac{5}{8}$	9	10	27	10	18
4	20	11.00	62	39	12	$31\frac{1}{2}$	$\frac{7}{8}$	4	$\frac{3}{4}$	5	$\frac{5}{8}$	8	12	30	12	$23\frac{1}{2}$

Item	Total Height H	Right Cantilever										Unit Pressure on the Soil	
		For Plain Round Bars P					For Deformed Square Bars P						
		Dimensions of Slab		Size of Round Bars	Spacing	Length of Embedment e	Dimensions of Slab		Size of Square Bars	Spacing	Length of Embedment e		
	Feet	Thickness at End E Inches	Maximum Thickness F Inches	Inch	Inches	Inches	Thickness at End E Inches	Maximum Thickness F Inches	Inch	Inches	Inches	Maximum Pounds per Square Foot	Minimum Pounds per Square Foot
1	8	6	$13\frac{1}{2}$	$\frac{7}{16}$	5	11	6	$8\frac{1}{4}$	$\frac{3}{8}$	$4\frac{1}{2}$	12	2,450	0
2	12	10	$18\frac{1}{2}$	$\frac{5}{8}$	$4\frac{3}{4}$	20	8	14	$\frac{5}{8}$	$6\frac{1}{4}$	21	3,700	0
3	16	12	$28\frac{1}{2}$	$\frac{3}{4}$	5	29	10	$19\frac{1}{2}$	$\frac{3}{4}$	$6\frac{1}{4}$	24	5,000	0
4	20	14	$35\frac{1}{2}$	$\frac{7}{8}$	$4\frac{1}{4}$	36	12	$29\frac{1}{2}$	$\frac{7}{8}$	$5\frac{1}{2}$	29	6,100	.300

NOTE.—In the retaining-wall design the following working stresses and conditions are assumed:
Compression in concrete, 500 pounds per square inch. Tension in steel, 16,000 pounds per square inch. Bond of plain bars to concrete, 80 pounds per square inch. Bond of deformed bars to concrete, 120 pounds per square inch. Shear involving diagonal tension, 40 pounds per square inch. Slope of earth above wall, 35°; weight of earth, 100 pounds per cubic foot.

Courtesy of the Atlas Portland Cement Company, New York.

86. In Table I dimensions and reinforcement for **T**-type retaining walls are given, which will be found useful when designing retaining walls of a simple character. When the problem is complex, however, the designing of the wall should be referred to an engineer who is thoroughly familiar with such work, as it is not customary for architects to design any but the most simple gravity walls. It will be noted that in Table I sizes and spacing for either plain round, or square deformed bars are given, so that either may be used.

MATERIALS

87. The materials that are best adapted to the construction of retaining walls of the gravity type are stone and concrete, as they are heavy, and in this type it is the weight of the material that enables the wall to resist the lateral pressure of the adjoining soil. If brick is used for such walls the bricks should be hard burned so that they will not absorb moisture and thus cause the wall to deteriorate when exposed to the frost. As previously stated, concrete reinforced with steel is the only material that is used for the **T**-type retaining walls.

CONSTRUCTION

88. Excavation. — Excavations for retaining walls should be of ample size and proper shape for the work contemplated. Soil that is likely to break away and fall into the excavation should be supported during the construction of the wall in a manner similar to that described under the head of Bracing the Soil in connection with the subject of Area Walls.

89. Construction.—Retaining walls formed of stone or brick should be constructed in the same general manner as described under the head of Area Walls. Only cement mortar should be used for this construction and all joints and crevices should be thoroughly filled with the mortar and carefully pointed. If the wall is to be of concrete, however, wooden forms will be required and the construction of the forms and the wall will be similar to those previously described.

The wall shown in Fig. 53 is of the gravity type, with offsets formed in the back of the wall. Stone for such a wall should be large and partially squared, so that the joints and crevices may be small and easily filled with the mortar. The joints of such walls should be carefully pointed. Stones selected for footings should, if possible, be larger than those used in the wall and should break joints with the wall stone, as shown at *e*. The filling *f* on the offsets at the back of the wall should be of cinders or gravel, so that the water will drain to the offsets and through the chases *g* to the face of the wall. Openings of this character are called *weep holes*. Pipes of glazed tile are sometimes used for weep holes; also iron pipes, but the rust from the iron pipes will disfigure the wall.

The top of such a retaining wall should be protected by means of a coping, as shown at *h*.

90. A gravity-type, plain-concrete wall with a straight face and back is shown in Fig. 54. The footing course of this form of wall is usually cast independent of the wall, as this method facilitates the construction of the wall forms. It is necessary, however, to construct the footing in such a manner that it will be anchored and bonded to the wall after the wall is cast. To obtain this bond a groove, as shown at *a*, is usually formed in the top of the footing which later becomes filled with the concrete of the wall and thus a tongue-and-groove joint is formed between the wall and footing. This form of joint prevents any possibility of the wall sliding on the footing. It is also desirable to provide anchors between the footing and the wall, as shown at *b*, to resist the forces which tend to cause the wall to topple over. These anchors may be of $\frac{3}{4}$-inch steel bars, spaced about 2 feet on centers and formed as shown.

Walls of this character are made in sections one at a time by placing a partition in the forms at the point where it is desired that the joint shall occur and then pouring the concrete into the forms so as to cast the first section. This partition should be designed to form a groove in the end of this section as shown at *c*. When the concrete of this section has become set, this partition is removed and located at the point where the next joint is to be formed, and this operation is continued until the various sections forming the wall have been completed. After the partition has been removed from a section that has been just cast, sand should be sprinkled over the end of this section, or a piece of tarred paper inserted, to prevent the new concrete from bonding with that which has been previously cast.

The openings shown at *d* are weep holes through which water may drain from the cinder filling *e* back of the wall. Where there is likely to be surface water from an adjoining bank of soil, a gutter as shown at *f* is often laid to carry away this water to a point beyond the end of the wall.

The **T** type of retaining wall shown in Fig. 55 requires wooden forms so constructed that the footing and the wall may be cast at the same time. The reinforcing bars should be located in their proper positions and so secured in place that they will not be misplaced when the concrete is deposited. Gravel used for the concrete of these walls should be small in size and the mixture thoroughly puddled as it is placed, so that the concrete will entirely enclose the steel and form a smooth even surface on the face of the wall.

Weep holes of the same character as previously described are usually formed in these walls.

91. Back filling of soil adjoining all walls should be tamped as it is deposited, so that the filling will be as compact as the natural soil adjoining, and the surface of the filled parts should be made with a slope to drain water away from the wall wherever this is possible.